Study into the viability of e-mobility and requirements for the strategic roll out of electric vehicles in South Africa

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DECLARATION

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ABSTRACT

The electrification of transportation through the introduction of electric vehicles in the South African market can potentially reduce oil dependency and lead to the possible reduction of carbon footprints through lower annual CO_2 emission rates. The key question is if the introduction of electric mobility will be financially viable in South Africa and, if so, what business model should be followed.

To answer this question cost analysis and total cost of ownership calculations have been modelled based on 8 scenarios. All scenarios consisted of different variables in order to identify the key variables affecting the financial viability of e-mobility. Global market forecasts and governmental incentives and the effect of it on the total cost of ownership have been researched and compared to proposed South African incentives by the DTI. Battery recharging techniques and different battery and vehicle types have been evaluated. Furthermore, the impact on the national grid has been studied, as well as the potential e-mobility value chain and the associated direct job creation.

The findings in this thesis illustrate that the introduction of e-mobility can be viable if it is based on a model 2 based business model. Early adopters will preferably use level 2 home charging in the introductory stage. The commencement of demonstration projects is to shed more light on uncertainties and to overcome potential limitations by gathering the desirable data and valuable insights regarding driving and charging preferences and habits.

Cost analysis has shown that the biggest aspects affecting the total cost of ownership are initial battery costs, battery price reduction, and vehicle acquisition costs, while operating cost are predominantly relying on the difference between fuel and energy prices. The analysis has shown that governmental incentives don't significantly affect e-mobility's viability.

OPSOMMING

Die elektrifisering van vervoer deur die gebruik van elektries aangedrewe motorvoertuie het die potensiaal om Suid Afrika se afhanklikheid van olie asook die CO_2 impak wesenlik te verminder. Die vraag is egter of die implementering van elektriese vervoer finansieël aantreklik is vir Suid Afrika, en indien wel watter spesifieke besigheidsmodel toepaslik sou wees.

Om die vraag te beantwoord is 'n koste analise gedoen wat kyk na die verskillende kostes en tenologië. 'n Kostemodel om die totale koste van eienaarskap te bepaal is gedoen, baseer op 8 verskillende senarios. Deur die verskillende senarios is hoof veranderlikes bepaal wat 'n invloed het op die bekostigbaarheid van elektrifisering. Globale mark vooruitskattings asook regeringsinisiatiewe is ondersoek, en vergelyk met Suid Afrikaanse voorstelle en moontlike aansporings rondom die onderwerp soos uiteengesit in DTI beplanningsdokumente. Verskillende battery tipes, verskillende elektriese motors asook herlaaitegnologië is evalueer. Die impak van die gebruik van elektries aangedrewe voertuie op die SA elektrisiteitsnetwerk is ondersoek, en die moontlikhede van waardetoevoeging oor die hele waardeketting en werkskepping is op 'n hoë vlak bespreek.

Die bevindinge van hierdie tesis dui daarop dat e-vervoer ("e-mobility") wel lewensvatbaar kan wees mits 'n spesifieke besigheidsmodel (model 2 in die dokument) gevolg word. Aanvanklik sal gebruikers verkies om vlak 2 tuis herlaaitegnolgie te gebruik. Om die onsekerhede van moontlike gebruikers uit die weg te ruim, asook om steekproefdata te bekom vir verdere ontleding oor gebruikersgedrag, is dit noodsaaklik om elektrifiseringsprojekte binne 'n klein geografies afgebakende gebied te implementer.

Die kosteanaliese het getoon dat die aanvanklike batterykoste, die toekomstige prysafname in hierdie prys, asook die voertuigprys self die grootste bydraes maak tot die totale koste van eienaarskap. Loopkosteverskille word hoofsaaklik bepaal deur die prysverskille tussen elektrisiteit en olie/brandstof. Laastens toon die ondersoek dat finansiële aansporings van regeringskant af nie 'n wesenlike verandering aan die lewensvatbaarheid van e-vervoer teweeg bring nie.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my study leader Mr Konrad von Leipzig for his help, support, time and useful insights as well as the pleasant times and memories he has given me throughout my stay at the Stellenbosch University. Special thanks goes out to my friends, who gave me through their hospitable nature the most amazing time during my time in South Africa, my family for all the moral and financial support and my girlfriend Lara Felske for always being there when needed the most. Without the support of all of them this dissertation would never have been finalized.

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GLOSSARY

BEV	Battery Electric Vehicle
ICE	Internal Combustion Engine
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
HEV	Hybrid Electric Vehicle
EREV	Extend Range Electric Vehicle
AC	Alternating Current
DC	Direct Current
SOC	State Of Charge
IPT	Inductive Power Transfer
EMI	Electro Magnetic Interference
MF	Magnetic Field
ICT	Information and Communication Technology
GEV	Grid Enabled Vehicle
V2G	Vehicle To Grid
G2V	Grid to Vehicle
LDV	Light Duty Vehicles
MDV	Medium Duty Vehicles
HDV	Heavy Duty Vehicles
IDC	Industrial Development Corporation

1 CHAPTER ONE – BACKGROUND AND INTRODUCTION

1.1 The history of electric vehicles

Although it's uncertain who invented the first electric vehicle (EV), several inventors have been given credit. In the early 1800s the first demonstration electric vehicles were developed. Hungarian-born Ányos Jedlik invented a small-scale model car powered by an electric motor that he designed himself. Later, in 1835, the Dutch professor Stratingh of the University of Groningen in the Netherlands designed a small-scale electric car based on the physical principles of the British Michael Faraday. The electric vehicle was constructed by his instrument maker, Christopher Becker, and can been seen as the forerunner of the modern days EV (Univeristy of Groningen, 2011). By the end of the 19th century, EVs became commercially available. However, due to range and refuel differences, EVs have not enjoyed a big success like the internal combustion engine (ICE) vehicles. By the 19th century rechargeable batteries had been invented and EVs became more widely used. According to Larmine and Lowry (2003), performance rates of electric vehicles, at this stage, were better than those of ICE's and steam engines. They were relatively reliable and started instantly whereas ICE vehicles at the time were unreliable, smelly and needed to be manually cranked to start. By the 1920s cheap oil and the self-starter for the ICE (invented by Charles Francis Jenkins) became widely available and proved to be a more attractive option for propelling vehicles. Until today, ICE vehicles have been more successful mainly because of the difference in specific energy of petroleum fuel and batteries. It takes about 45 litres of petrol, with a mass of around 40 kg, to give a typical ICE vehicle a range of 450 km. To achieve the same range in a lithium ion battery powered vehicle, a battery pack with a weight of 800 kg would be required (Larmine & Lowry, 2003). Another important aspect is the time that is required to recharge an EV compared to the time it takes to fuel up an ICE vehicle. A further limiting feature is the price of batteries. These factors have been the predominant reasons why ICE vehicles have been favoured in the 20th century. According to Larmine and Lowry (2003), early on in the development of electric vehicles the concept of the hybrid vehicle was developed, in which an internal combustion engine driving a generator was used in conjunction with one or more electric motors. These were tested in the early 20th century but have recently come back to the fore.

Concerns regarding the environment, in terms of carbon dioxide and exhaust emissions, made electric powered vehicles popular again in the late 1900s. These days, local governments are striving towards cleaner, quieter cities and some of them are welcoming zero emission vehicles with tax incentives. Technical developments on battery power, recharging speeds and lifetime have been improved although not as much as many people wished. The developments of these battery aspects are still in an early stage.

1.2 Introduction

Electrification of transportation is a promising way to reduce CO_2 emissions and oil dependency in South Africa. The transport sector is a major contributor to CO_2 emissions. Gasoline and diesel fuels are derivatives of crude oil and are used, amongst others, in internal combustion engines to power conventional vehicles. Crude oil represents the single largest item on South Africa's import account. According to the Department of Energy (DoE), South Africa imports almost 95% of its crude oil requirements from the Middle East and Africa due to limited oil production. Figure 1 illustrates a comparison between crude oil production and consumption. South Africa only started producing and refining oil on a small scale in 1998 and, until 2009, produced on average 24,85 thousand barrels per day (CIA, 2012).

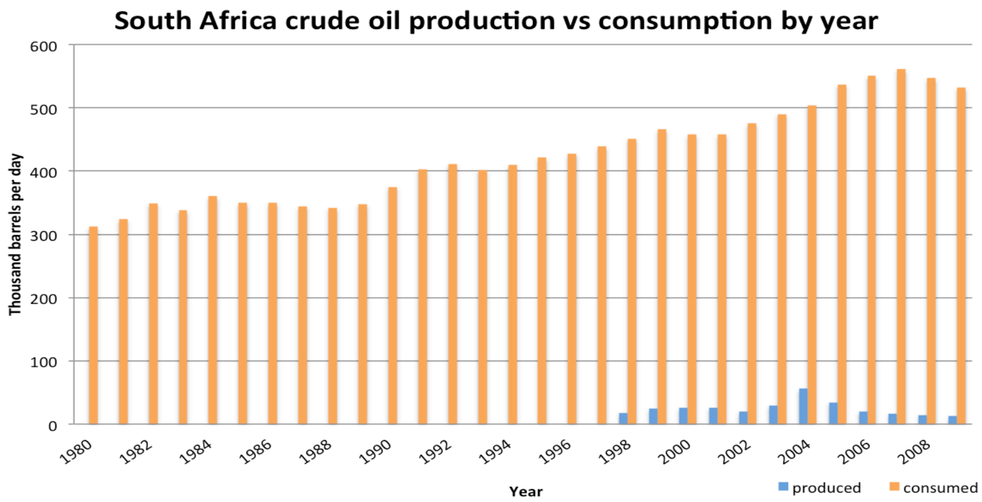


Figure 1: Comparison between crude oil consumption and production

Domestic oil production falls far short of meeting the country's requirements and, according to Nkomo (2009), there are no economical and readily available substitutes to replace imported crude oil on a large scale as of yet.

Electric vehicles use electricity as a source of energy to propel the vehicle. This electricity is stored in an internal battery and can contribute to a reduction of CO_2 emissions and oil dependency. Eskom, the largest electricity producer of South Africa, produces 95% of all electricity in the nation (Eskom, 2011). The average overproduction between 2000 and 2011 was 9,14% and increased over the past 10 years. A total overproduction in 2011 of 25 billion kWh has been observed. Eskom stated that if 120 000 EVs were utilized the impact on the grid would be less than 2%. This unutilized energy can be used for electrical vehicle charging and can, theoretically, reduce oil dependency while not stressing the national power grid.

1.3 Aim and objectives

The aim of this thesis is to research if the introduction of e-mobility in South Africa can be accomplished, what should be considered, what is required in order to implement it and to make it a viable alternative way of transportation. The technical aspects of conventional and electric vehicles, worldwide progress and governmental support in the form of incentives will be studied. The DTI's (Department of Trade and Industry) position paper on government's proposed interventions to establish/support the EV industry in the Republic of South Africa will be evaluated and South Africa's current situation is compared to the global market development.

Different business models, the challenges that the electrification market is facing and vehicle recharging requirements will be examined to determine potential realisation or failure of implementation. In order to identify the key variables affecting the viability of e-mobility 8 total cost of ownership scenarios with different conditions will be modelled.

The importance of rollout of electric vehicles and demonstration projects in the coming years is investigated. This will determine if EV consumer awareness and public education campaigns must be developed and if demonstration projects can penetrate existing markets by creating a "demand pull" for the technology, as well as a "technology push", or learning gains that improve the rate of technological progress (Coalition, 2009). This means connecting all stakeholders such as the electricity suppliers, vehicle and battery manufacturers, in order to evaluate business models for charging infrastructure in a small scaled learning/demonstration project before implementing e-mobility in bigger cities such as Johannesburg or Cape Town. The possibility to turn the Stellenbosch municipality into a suitable area for such a scaled project has been studied.

2 CHAPTER TWO - LITERATURE REVIEW

This chapter reviews and compares four different types of vehicle configurations and propulsion systems; specific refuelling and recharging techniques; the working of smart grids; and the electric mobility value chain.

2.1 The internal combustion engine

There are many different types, configurations and layouts of combustion engines, such as two- four- and six-stroke and diesel. A traditional internal combustion engine vehicle stores a liquid fossil fuel, like gasoline or diesel, on-board in a fuel tank. Fuel is combusted together with an oxidizer, like oxygen, in the combustion chamber of the engine, which delivers mechanical energy to the axle to propel the vehicle. Vehicles with an ICE propulsion system can travel significantly further on one full tank than EVs can with a fully charged battery pack. This is due to the high density of gasoline and the ability to store substantial volumes of fuel in the on-board fuel tank. Although the efficiency of internal combustion engines is improving rapidly in terms of fuel usage, today's ICE’s are highly inefficient. Internal combustion engine automobiles turn less than 20% of the energy in gasoline into power that propels the vehicle. The rest of the energy is lost to engine and driveline inefficiencies and idling (Electrification Coalition, 2009).

2.2 Electric Vehicles

These days there are a wide range of electric vehicles (see Appendix A1) on the market, from Original Equipment Manufacturers (OEMs) to small-scale manufacturers, all with variable performance and driving preferences ranging from preliminary duty EVs to sport EVs like the Tesla roadster. EVs make use of one or more electric motors for propulsion and the required electricity can be stored, as well as generated, in different ways. The high efficiency level of electric vehicles is mainly due to the capabilities of electric motors which can already turn as much as 90% of the energy in electricity into mechanical energy. This high level of efficiency is the driving force behind the reduced energy consumption and lower emissions of EVs (Electrification Coalition, 2009). The most conventional way of charging is a battery electric vehicle (BEV). A BEV, or full EV, stores its electricity in on-board battery packs that are charged through the electric grid. Other ways of charging include solar power by using solar cells, fuel cells, inductive power transfer (IPT); and hybrid EVs which make use of an internal combustion engines to charge the battery. Electric vehicles do not require a transmission since the electric motor delivers high torque even at low speeds (Carbon Descent, 2009). Figure 2 illustrates the basic difference in engine/motor configurations between ICE, HEV, PHEV and EVs.

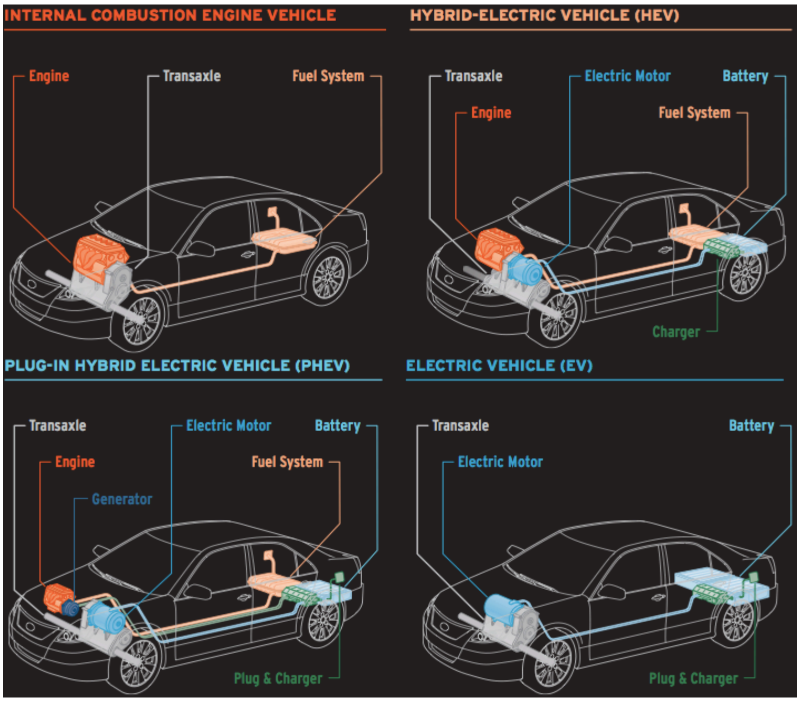


Figure 2: Schematic of vehicle configurations (Electrification Coalition, 2009)

2.2.1 BEV – battery electric vehicle

A BEV is powered solely by electricity stored in on-board batteries, doesn't feature an on-board engine, and is charged by plugging into the grid through magnetic coupling or by swapping the battery. The different charging techniques are discussed in paragraph 2.3.

Figure 3: The Nissan Leaf, a full battery powered electric vehicle

Electric vehicles rely on one or more electric motors that receive power from an on-board battery to provide the vehicle's propulsion and operation of its accessories. The rechargeable batteries drive either direct current (DC) or alternating current (AC) motors. DC motors were used in the beginning of e-mobility and are less common than the AC motors. The reason for this is a higher efficiency rate, better reliability and, unlike DC motors, they do not have contact brushes that could result in wear or tear and, therefore, need replacing more frequently. AC motors have the ability to generate power out of braking force. This is called regenerative braking. By using the momentum of the EV, for example, by driving downhill or by lifting a foot of the accelerator pedal, will cause the EV to decelerate whilst the vehicle is still moving. The generated energy can be recovered by converting its kinetic energy while slowing down and storing it in the battery pack. In conventional braking systems the excess kinetic energy produced by friction is converted into heat and is not stored but wasted. BEV batteries are typically larger than batteries in HEVs or PHEVs to support vehicle range.

2.2.2 HEV – hybrid electric vehicle

HEVs retain the use of an ICE and, therefore, require a liquid fuel tank. Additional energy is stored in a battery from which electricity flows to an electric motor. The motor transforms electrical energy into mechanical energy, which provides torque to the wheels in the same way as it's done in BEV configuration (Electrification Coalition, 2009).
There are 3 types of HEVs:

- Parallel hybrid system: both the engine and the motor provide torque to the wheels.

- Series hybrid system: only the electric motor provides torque to the wheels. The ICE is not directly connected to the wheels but powers an on-board generator producing electricity that can be used to charge the battery.

Figure 4: The Audi A1 e-tron HEV

- Series-parallel (full) hybrid: Combines the advantages of a series and a parallel hybrid through a power split device. The power split device works as a gearbox and can allow either one or both the ICE and electric motor to power the vehicle or to drive the generator. The ICE can either provide torque directly to the wheels or generate electricity to be stored in the battery.

2.2.3 PHEV - plug-in hybrid electric vehicle

Like traditional hybrids, PHEVs retain the use of an internal combustion engine and fuel tank while adding a battery and electric motor. However, PHEVs utilize much larger batteries, which can be charged and recharged by plugging into the electric grid. PHEV batteries are capable of powering the vehicle purely on electricity at normal speeds over significant distances (approximately 65 kilometres) without any assistance from the ICE. When the battery is depleted, PHEVs use the ICE as a generator to power the electric motor and extend their range by several hundred kilometres. PHEVs can be configured as a series hybrid system or a power split system. PHEVs have an extended range compared to the BEV, and make it possible to drive greater distances with the use of an ICE whilst still having EVs potential to reduce CO_2 emissions. One of the most common PHEVs is the Toyota Prius which is illustrated in Figure 5.

Figure 5: Toyota Prius PHEV

2.3 Types of vehicle re-charging

2.3.1 Plug-in charging

In conventional charging, or plug-in charging, the electric vehicle can be charged directly through plugging in a de-energized connection cord from the cars inlet to the standard 110 V or 220 V wall socket. The input voltage coming from the electrical grid is sent at the highest possible current into the battery for recharging without overheating the battery, and maximizing its efficiency. A higher current results in a faster recharge but can also effect the battery temperature and cause the battery to overheat if not monitored. Normal voltages used for home charging ranges between 110–240 V or 16-80 A, and is commonly known as level 1 and 2 charging. Fast charging, or level 3 charging, ranges from a proposed 200–600 V and 240 A. The levels of charging are discussed in more detail in paragraph 2.4.

2.3.2 Wireless Charging

Another type of charging is induction charging, also referred to as wireless charging (see paragraph 2.4.1). Wireless charging, as Dixon and Bhargava describe it, uses a charging station to transfer high voltage and current directly from the grid into an inductive paddle with an electro-magnet that acts as half a transformer. The other half is situated inside the electric vehicle and once full contact is made between the two magnets, the current is allowed to flow across and into the battery, charging at a higher rate due to the charging stations direct power grid connection (Dixon & Bhargava, 2010).

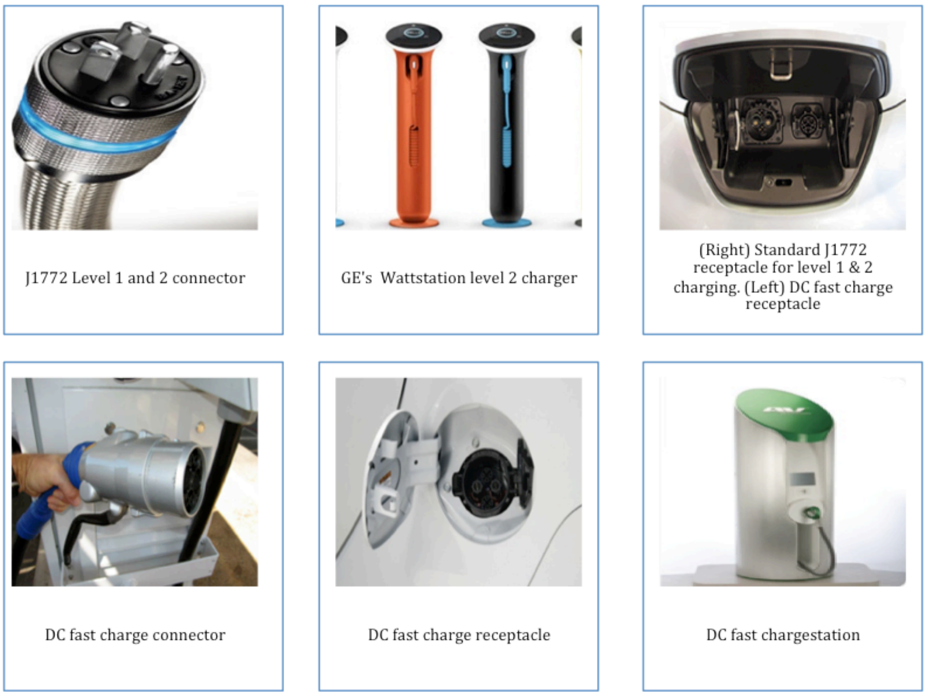
2.3.3 Battery swapping

This method of charging is based on a leasing model where the vehicle owner leases the battery from a service provider. The service provider remains the owner of the battery and the vehicle owner can swap depleted for recharged batteries at dedicated swapping stations. A more detailed model of this technique is discussed in paragraph 2.4.3.

2.4 Understanding charging

2.4.1 Level 1, 2 and 3 charging

The vehicle charger is the device that connects the electric vehicle with the electrical grid, through which the battery pack in the vehicle is charged. The device that the vehicle connects to is referred to in the technical literature as electric vehicle supply equipment, or EVSE. Currently, there are three different charging speeds which are referred to as level 1, 2, and 3, or slow, faster and fastest charging. Different charging levels are based on the available power. For instance, the USA uses the NEMA outlet, which is commonly known as the traditional house plug. This level (1) of charging is relatively slow with 110-120 V and a maximum 16 A. Level 2 is faster than level 1 charging, and it is more likely that EV users will choose to charge their vehicles at level 2 charging due to the fact that the voltage used for level 2 (220-240 V) is also used in many home appliances like electric driers, washing machines and electric ovens. Level 3, also known as direct current (DC) charging, is designed for commercial applications and with a charging range from 30 kW to 240 kW it can fully charge an average sized battery in less than 10 minutes. It is expected that level 3 charging will be significantly more expensive then level 1 or 2 charging and will be manufactured for commercial establishments (Electrification Coalition, 2009). Figure 6 illustrates the different charging poles and connectors.



J1772 Level 1 and 2 connector

GE's Wattstation level 2 charger

(Right) Standard J1772 receptacle for level 1 & 2 charging. (Left) DC fast charge receptacle

DC fast charge connector

DC fast charge receptacle

DC fast chargestation

Figure 6: Illustrations of level 1, 2 and 3 charging pols and connectors

Safety issues will require EVSE standards instead of simply connecting a charged cord to an EV.

The following is a list of standard EVSE safety features (PG&E, 2009):

- An EV will not start if it is still plugged into the charger;
- Before the charger can be disconnected, the cable must be de-energized;
- The vehicle inlet is de-energized until the driver attaches the unique connector to the vehicle;
- The EV connector cannot be used with other appliances;
- Monitors and a ground-fault circuit interrupt (GFCI) shut down the electricity supply if they sense a potential problem; and
- For the few battery types that emit potentially explosive gases, building codes require ventilation to eliminate risks.

The EVSE standard in the USA is known as J1772. Although there are many charging points in Europe, standards for EVSEs and charging modes have not yet been agreed upon. The international standard specification entitled IEC61851-1 ed2.1 is still under development (PG&E, 2009). Table 1 displays charging methods and configuration in the USA.

Table 1: Charging methods and configurations. Data adapted from (Harrop & Zervos, 2011) and (SAE, International, 2011)

AC charging		Estimated charging time	DC Charging		Estimated charging time
AC level 1	120 V AC single phase; max 16A; max 1.92 kW	PHEV: 7hrs (SOC - 0% to full) BEV: 17hrs (SOC – 20% to full)	*DC level 1	200-450V DC; current <= 80A; power <= 19.2kW max 36 kW	Est. charge time (20 kW off-board charger): PHEV: 22 min. (SOC - 0% to 80%) BEV: 1.2 hrs. (SOC – 20% to 100%)

AC level 2	240V AC single phase; max 80A; max 19.2 kW	**Est. charge time for 3.3 kW on-board charger** PHEV: 3 hrs (SOC - 0% to full) BEV: 7 hrs (SOC – 20% to full) **Est. charge time for 7 kW on-board charger** PHEV: 1.5 hrs (SOC - 0% to full) BEV: 3.5 hrs (SOC – 20% to full) **Est. charge time for 20 kW on-board charger** PHEV: 22 min. (SOC - 0% to full) BEV: 1.2 hrs (SOC – 20% to full)	*DC level 2	200-450V DC; max 200A; max 90kW	Est. charge time (45 kW off-board charger): PHEV: 10 min. (SOC - 0% to 80%) BEV: 20 min. (SOC – 20% to 80%)
AC level 3	Not defined yet. Maybe in the near future, might cover AC three phase >20kW		*DC level 3	TBD, may cover 200-600V DC up to 400A and 240 kW	200 - 600V DC (proposed) up to 240 kW (400 A) Est. charge time (45 kW off-board charger) BEV (only): <10 min. (SOC* - 0% to 80%)
***DC level charging not yet fully operational according to above mentioned sources. Notes: Voltages are nominal configuration voltages, not coupler ratings. Rated Power is at nominal configuration operating voltage and coupler rated current. Ideal charge times assume 90% efficient chargers, 150W to 12V loads and no balancing of Traction Battery Pack. BEV (25 kWh usable pack size) charging always starts at 20% SOC, faster than a 1C rate (total capacity charged in one hour) will also stop at 80% SOC instead of 100%. PHEV can start from 0% SOC since the hybrid mode is available.**					

Figure 7 shows an overview of a typical commercial charging process. Buildings and landmarks like supermarkets, warehouses and shopping malls are expected to create dedicated EV charging parking spaces; especially in the early stage of EV adoption as this could attract customers to their establishments. The author's opinion is that promotions, like free charging when the costumer spends over a certain amount, can be attractive for the consumer to visit these particular malls or warehouses instead of being offered a free parking facility. Once parked, the EV can be charged by connecting the power cord to the EVs power inlet. While shopping, the pre-chosen charging percentage, i.e., 30% or 45%, will be charged into the vehicle and, through a mobile phone or other Wi-Fi/3G enabled device, a payment and charging notification can be sent to the vehicle owner. Companies such as Mobile NOW, Liberty PlugIns and QuickPay already have payment and charging applications like these successfully operating in the Unites States (Red Orbit, 2012).

Figure 7: A typical charging process overview

Charging stations should facilitate the ability for normal and fast charging, either by electricity from the conventional grid (see Figure 8) or via renewable energy sources like solar power (Figures 9 and 10). Figures 9 and 10 illustrate the Solar Groves developed by Envision Solar. These Solar Groves can be installed in parking lots all over the world to generate electricity for EV charging purposes and for night time illumination, both on green energy. Ultimately, this kind of solar energy rooftop will be a considerable advantage for large corporations and local governments with big company electric vehicle fleets.

Figure 8: Charging station proposed by Evoasis

Figure 9: Envision Solar 1

Figure 10: Envision Solar 2

2.4.2 Induction charging

In comparison to plug-in charging, inductive charging, better known as wireless charging, doesn't require charging poles or associated cabling. Inductive power transfer (IPT) is based on Ampere's and Faraday's laws. It uses a varying magnetic field to couple power across an air gap to a load without physical contact (Budhia, Covic, & Boys, 2010). EVs can be charged wireless by using magnetic coupled pads. When two induction pads are situated directly above each other, a strong alternating current in the transmitter coil generates a magnetic field which induces a voltage in the receiver coil. This voltage can then be used to charge a battery. Figure 11 demonstrates the basic principle of coupling in an inductive power transfer system. L1 is the transmitter coil and L2 is the receiver coil, both form a system of magnetically coupled inductors. An alternating current in the transmitter coil generates a magnetic field that induces a voltage in the receiver coil. The coupling is determined by the distance between the inductors (Z) and the relative size (D2/D). Not only the distance, but also the angle (B) between the coils and shape affects the coupling (Waffenschmidt & Van Wageningen).

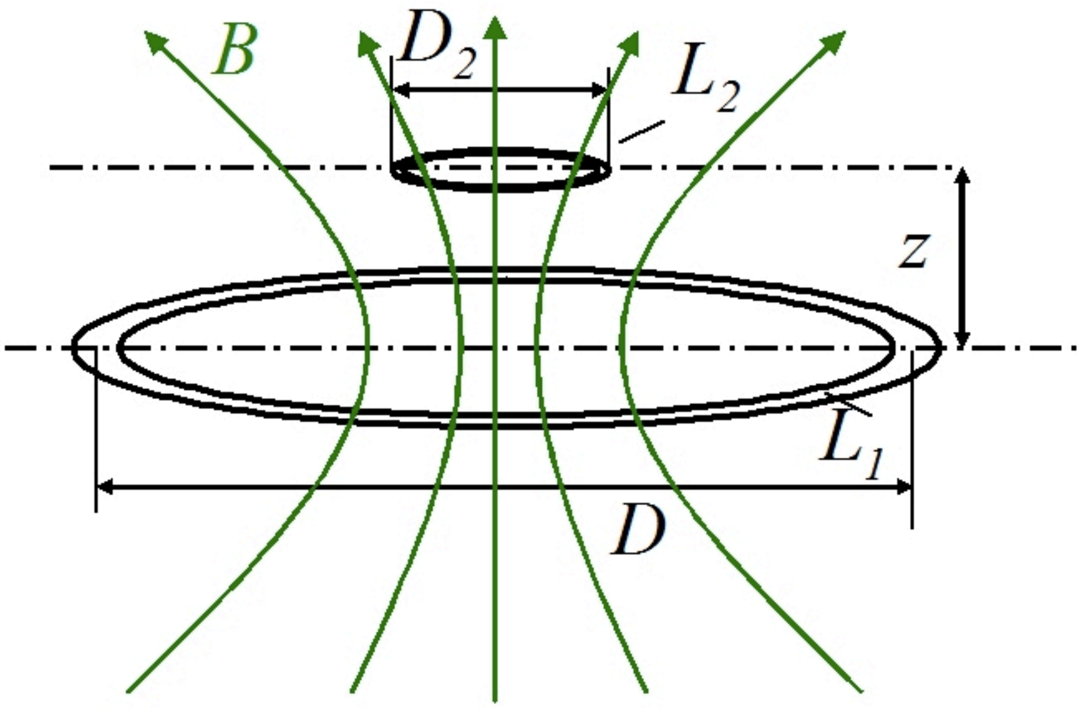


Figure 11: Typical inductively coupled power transfer system (Waffenschmidt & Van Wageningen)

Inductive charging produces no contaminants, is reliable, and almost maintenance free. Tables 2 and 3 describe the advantages and disadvantages of this charging method. IPT is not a new technology and has shown its capability and diversity for other purposes, like electrified monorails in assembly lines, sorting facilities in mail-order houses, floor conveyors in engine assembly lines, and charging of electric toothbrushes.

Figure 12 illustrates HaloIPT's, a United Kingdom based company, inductive power transfer system.

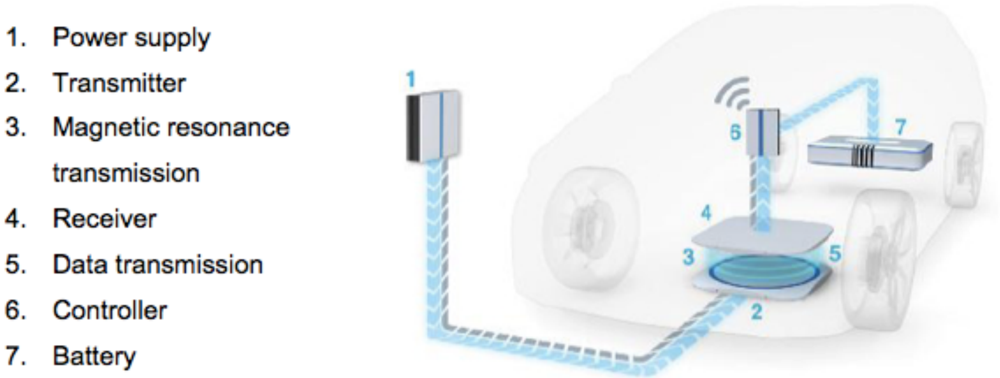


Figure 12: IPT charging system developed by HaloIPT

In short, the high-frequency generator takes a mains voltage input (240 V AC at 50/60Hz) and produces a high-frequency (>20kHz) current. The output current is controlled and the generator may be operated without a load. The efficiency of the generator is high at over 94% at 2kW. The current is sent to the transmitter and a strong alternating current in the transmitter coil generates a magnetic field. The receiving coil then picks up the current and is sent to the controller.

The controller takes power from the receiver pad and provides a controlled output to the batteries, typically ranging from 250 V to 400 V DC. The controller provides an output that remains independent of the load and the separation between pads. Without a controller, the voltage would rise as the gap decreased, and fall as the load current increased (HaloIPT, 2010).

The pad construction provides shielding of magnetic fields to prevent electromagnetic interference (EMI) within the vehicle and ensures levels of magnet field (MF) exposure are within the guidelines suggested by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). It's not necessary to be inch-perfect for the system to work. It makes HaloIPT's charging system a tolerant solution for powering an electric vehicle through both static charging and dynamic charging. Static charging means that people will be able to charge their vehicle by parking on the coil. The tolerance also make it possible to charge dynamically, that is, enabling electric cars to charge while they're on the move. This immediately opens up the vision of assured long distance travel with electric cars using HaloIPT's inductive charging method.

In order to gather more data regarding inductive charging, HaloIPT started a test case with inductive charging for public transport city busses in the city of Genoa in Italy. Figure 13 shows the IPT coils that are mounted onto the road surface, and busses that are equipped with IPT pick up coils.

Figure 13: IPT charging coils in Genoa Italy. (Conductix Wampfler, 2009)

Table 2: Advantages of IPT charging over conventional charging

Advantages	
Safety	• Wireless transfer is safe • Not harmful for humans or animals • Removes electrocution danger and tripping hazards • Cannot corrode or short circuit • No manual intervention
Durability	• Weather proof • Impervious to chemicals, debris • Vandal and theft proof
Ease of use	• No plugging-in or unplugging • Select charging and data options without leaving the car • Automatic charging through timer and account • Fast and slow charging with one system
Cost of infrastructure	• Lower maintenance cost as more durable • Lower insurance costs due to lower theft/vandalism risks.
	• Improved city aesthetics

Source: (HaloIPT, 2010)

Table 3: Disadvantages of IPT charging over conventional charging

Disadvantages	
General	• Losses during power transfer • Adding extra weight to the vehicle • High costs of new infrastructure

Source: (HaloIPT, 2010).

2.4.3 Battery swapping model

In contrary to the prior discussed level 1, 2 and 3 conventional charging and IPT wireless charging, Better Place, an American-Israeli company based in Palo Alto California, uses a different charging method. Instead of purchasing an electric vehicle including a battery, Better Place proposes a leasing model where the battery stays property of Better Place and provides this solution via a network of battery switch/swapping stations. The EV owner pays an annual subscription fee for this service. Figure 14 illustrates the Better Place battery-swapping model. An EV with a depleted battery pack enters one of the facilities and will be provided with a recharged battery that has the same specifications and shape. This is done by a robotic system that switches/swaps new batteries for depleted ones, cools and charge the depleted batteries in inventory. By doing this, Better Place also keeps control over the batteries and services requirements. The Better Place business model is further discussed in paragraph 4.2.2.

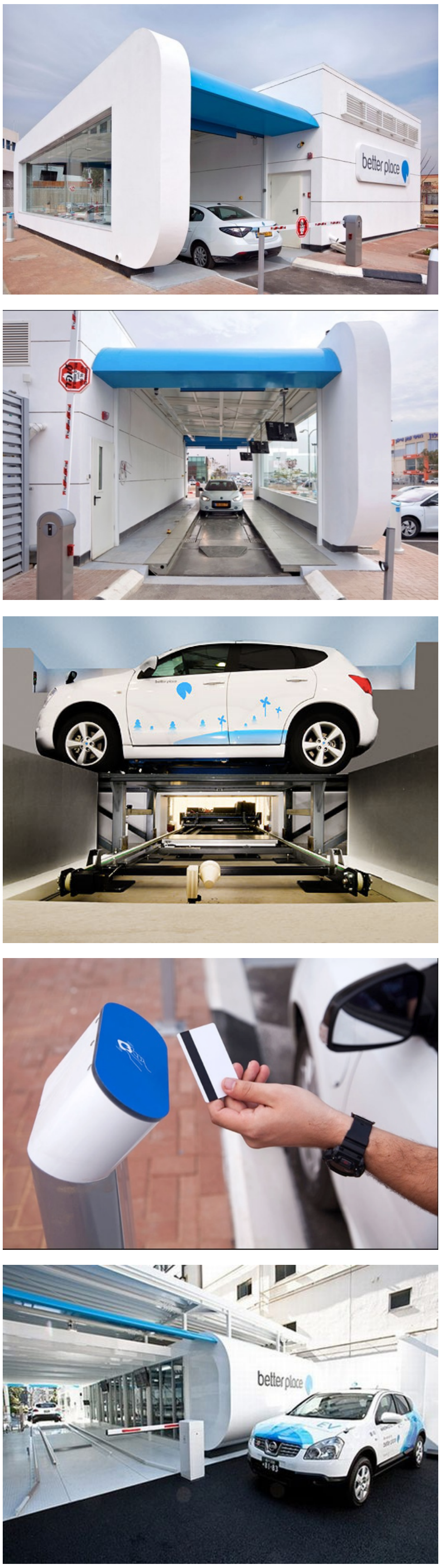


Figure 14: Overview of battery swapping

Many critics have expressed their concerns about the need for battery swapping stations as most consumers are expected to charge their vehicles at home by privately owned level 1 or level 2 charging systems. Auto manufacturers have concerns regarding safety, warranty and design homogenization/standardization (Brown, Mikulin, Rhazi, Seel, & Zimring, 2010). Also, consumers seem to be reluctant to swap batteries, as they don't know the charging history, current condition and expected lifecycle of the received full battery (Brown, Mikulin, Rhazi, Seel, & Zimring, 2010). Although there are barriers, a quick battery switch like this can make charging of public transport, like taxis and city busses, viable. A recent case study (Narich, Stark, Schutz, Ubbink, & Noom, 2011) in Yokohama in 2009, has shown that replacing a depleted battery for a full battery only takes 59.1 seconds.[1] Recycling of the batteries makes it possible for Better Place to sell it to the emerging 2nd hand market, better known as the second life battery market, if the battery is fully drained and doesn't come close to the "as new" specifications.

[1] According to Shai Agassi, CEO of better place, latest developments make it possible to swap a battery in 59.1 seconds. Opening speech Open House better place, Palo Alto, July 13, 2010

2.5 Battery types and infrastructural challenges

2.5.1 Vehicle and batteries

Whether plugging-in, wireless or swapping, all batteries eventually need to be charged after depletion. Extended research has been conducted over the past decades in battery technologies. Many different batteries, with different electrochemical compositions, have been designed and tested. Figure 15 shows a comparison of the specific power and energy of different battery technologies. There is an inverse relationship between specific energy and specific power, meaning that an increase in specific energy correlates with a decrease in specific power (IEA, 2011). Figure 15 also shows that lithium-ion batteries have a clear advantage over other electrochemical compositions when optimised for both energy and power density.

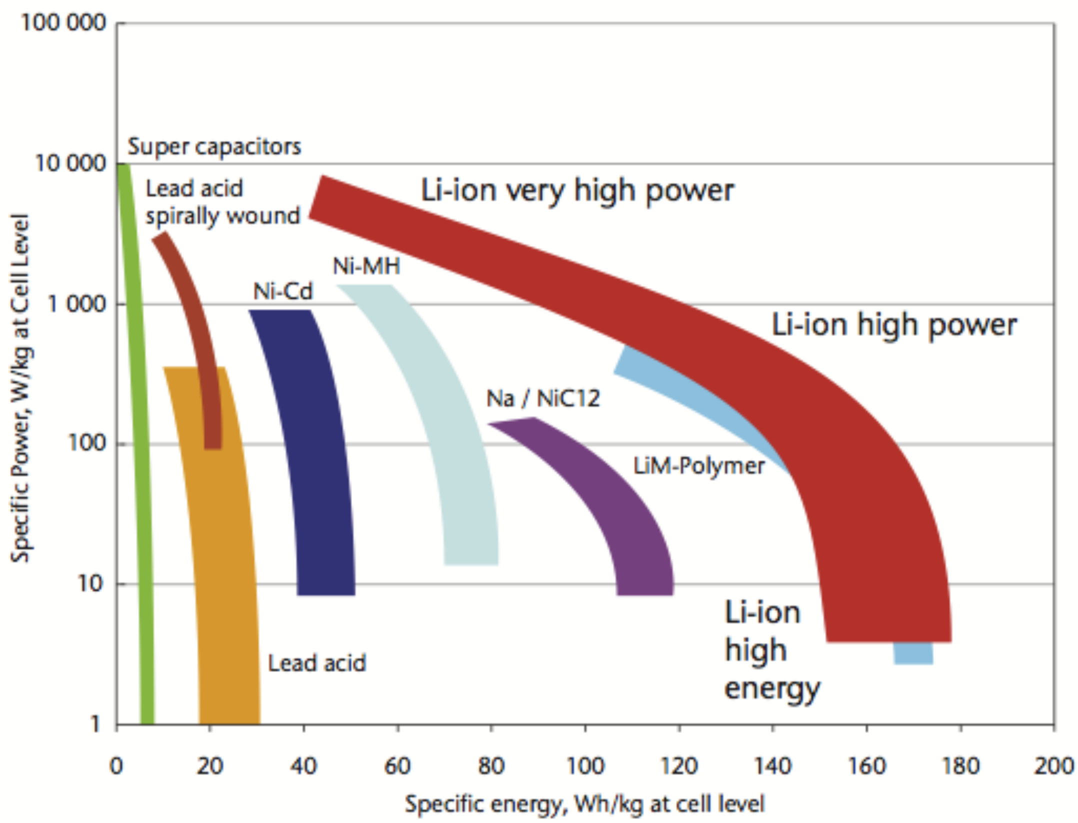


Figure 15: Specific energy and power of different types of batteries compositions (IEA, 2011, p. 12)

There are different types of lithium-ion battery configurations all with different specifications. Table 4 gives an overview of the strengths and weaknesses of these specifications. Appendix A2 shows a list of EV/PHEV manufacturers and partnering battery manufactures with production targets where available.

Table 4: Lithium-ion battery characteristics (IEA, 2011)

	Lithium cobalt oxide ($LiCoO_2$)	Nickel, cobalt and aluminium (NCA)	Nickel-manganese-cobalt (NMC)	Lithium polymer ($LiMn_2O_4$)	Lithium iron phosphate ($LiFePO_4$)
Energy Wh/kg or L	Good	Good	Good	Average	Good
Power	Good	Good	Good	Good	Average (Lower V)
Low T	Good	Good	Good	Good	Average
Calendar life	Average	Very good (if charge at 4.0 V)	Good	Poor	Poor above 30°C
Cycle life	Average	Very good (if charge at 4.0 V)	Good	Average	Average
Safety	Poor	Poor	Poor	Average	Good
Cost/kWh	Higher	High	High	High	High
Maturity	High	High	High	High	Low

Source: Guibert, Anne de (2009), "Batteries and super capacitor cells for the electric vehicle", Salt Groupe SA.

According to Dr Michal Vakrat Wolkin, Better Place's global head of battery technologies, a lithium-ion battery can be recycled with minimal environmental impact and more than 95% of the battery materials can be recovered and reused.

2.5.2 Charging infrastructure

ICE vehicle owners have always been able, from the day they owned a car, to fill up their fuel tanks whenever and almost wherever they needed to with nearly no need for additional planning. All electric vehicles have, until now, a smaller range compared to conventional ICE vehicles and, therefore, require re-charging more often and thus need a denser recharging network. In order to successfully facilitate the roll out of EVs in the nearby future, the development of EV charging infrastructure is important. The relationship between EVs and its required infrastructure can be seen as the chicken or the egg dilemma. Without OEMs manufacturing electric vehicles there will be no need to facilitate charging infrastructure and vice versa. OEMs such as GM, electricity providers, and governments, are still debating about the best possible charging method, billing systems, and business models, but for now there is no definite solution that can satisfy all stakeholders involved. This creates many uncertainties such as who will operate and own charging facilities and who will supply electricity. Demonstration plans are to shed more light on this matter and can accelerate the uptake of e-mobility.

2.6 The electric power sector

2.6.1 The smart grid

A smart grid is an integration of information and an electricity infrastructure network that distributes electricity. Smart grids monitor and manage the demand and capabilities of generators, grid operators, end users, and electricity market stakeholders, while minimizing costs and maximizing system reliability (Enerweb, 2011). Through Information and Communication Technology (ICT) infrastructures and the installation of smart meters, electricity providers can monitor the energy consumption of end users. Smart girds and meters also make it possible for energy providers to throttle down energy consumption to reduce strain on the grid when energy demand gets too high. The smart meters can remotely switch off appliances that consume electricity like streetlights, office building air conditioners, and smaller household appliances, like pool pumps and geysers, and can potentially reduce down time and black outs (State of green, 2011). Figure 16 illustrates an optimized electricity system.

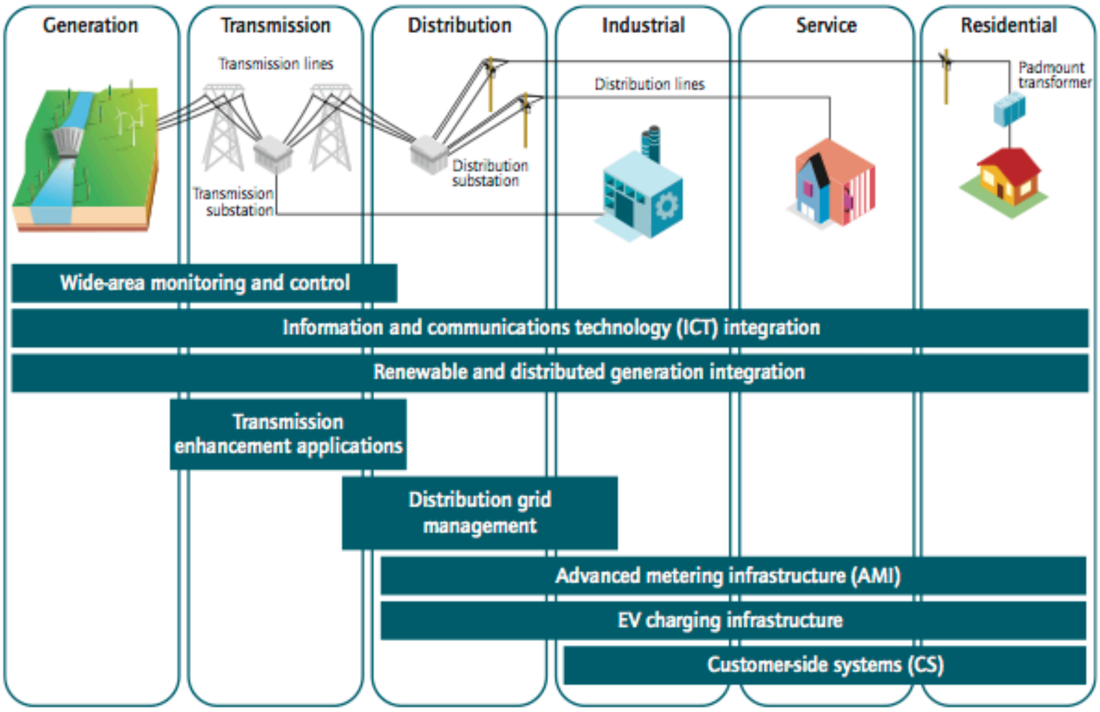


Figure 16: A schematic representation of an optimized electricity system (IEA, 2011)

Another main aspect of smart grids is the ability to accommodate two-way communication of energy distribution by facilitating grid connections for power generators. By establishing this it will be much easier to integrate renewable energy sources. One must think of energy generated out of biomass by local farmers, wind and hydro turbines, and photovoltaic panels. Other key features of a smart grid are the ability to reduce peak demands by shifting usage to off peak hours, reliability improvement, introduce consumer empowerment, dynamic pricing, availability of real time data, more efficient and easier to integrate renewable energy sources. By integrating renewables and facilitating EV and PHEV charging, CO_2 emissions can be significantly reduced. The deployment of smart grids is still in an early stage, and countries like China, United States, Italy, United Kingdom, Brazil and Germany have created demonstration plans to gather data in the areas of policy, standards and regulations, technology development, consumer engagement, and finance and business models (IEA, 2011). Examples of demonstration plans are further discussed in paragraph 3.2

2.6.2 Vehicle to grid and grid to vehicle configuration

The establishment of a smart grid could potentially bring great benefits to the electric vehicle charging infrastructure. By being able to connect a grid enabled vehicle (GEV) to the grid, the EV, hypothetically, can be a driving battery and it's on board stored electricity can be used for multiple purposes when needed. This two-way communication system with the grid is known as vehicle to grid (V2G) and grid to vehicle (G2V) technology and is illustrated in Figure 17. V2G makes it possible to send electricity back to the grid or to personal power storage facilities and can be used for domestic purposes.

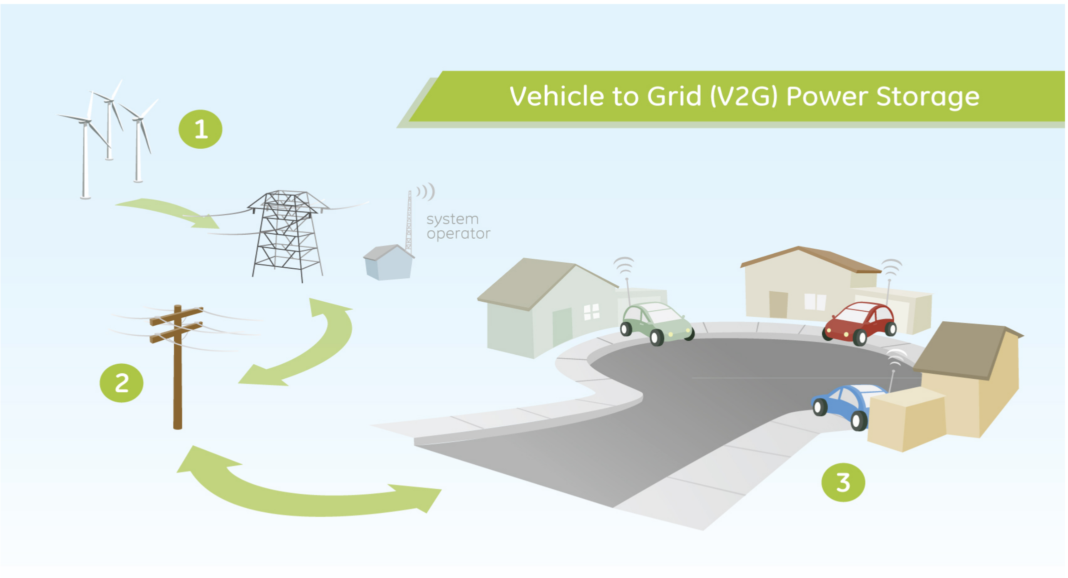


Figure 17: Schematic representation of vehicle to grid power storage (picture acquired from cleantechies)

1) Generated power albeit conventional or renewable is transferred to the grid.
2) Electricity flows from the grid to domestic power storage facilities or EV battery.
3) End users control when energy is uploaded or offloaded from the grid.

By doing this, consumers should be stimulated to charge their vehicles during off peak hours and thus preferably overnight (see Figure 18). This will reduce stress on the grid and can be more attractive for end users due to cheaper charging rates in off peak hours, potential refund from electricity provider, or may form part of a charging subscription plan.

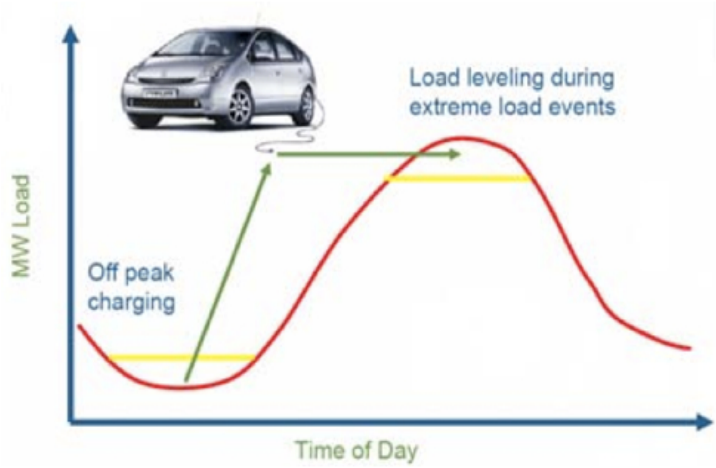


Figure 18: Schematic representation of V2G and G2V charging

2.7 The electric mobility value chain

By electrifying transportation, a whole new market erupts. This market is better known as the e-mobility market. Not only charging equipment, but charging stations, batteries and other vehicle components are required in order to successfully deploy an electrification strategy. Telematics and other value adding services such as cell phone applications, billing systems, V2G and G2V communication, and collection of various data that will improve the whole electrified transportation experience are just as important as the physical infrastructural requirement services. The e-mobility market is expanding rapidly and every day more OEMs and electricity providers are preparing themselves for the commercial uptake of this new kind of transportation and its needed value adding services. Business and research consulting group Frost & Sullivan recently produced a report about EV infrastructure and e-mobility and proposed a product and service portfolio, which is illustrated in Figure 19. According to them, 4375 theoretical owner/partnership combinations are possible.

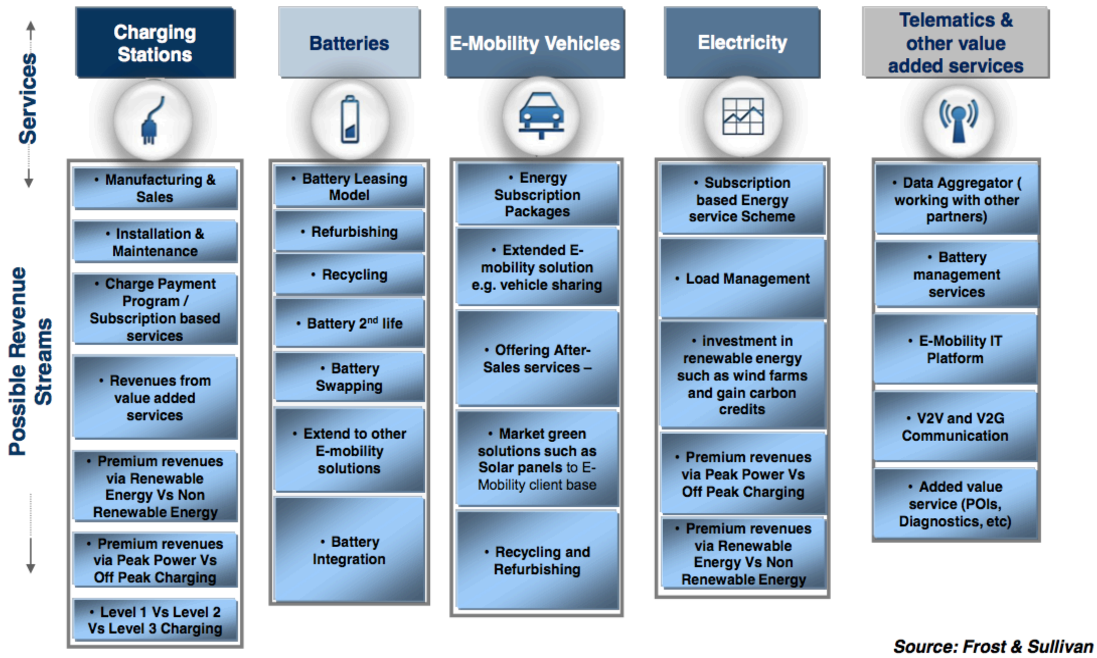


Figure 19: Example of product and service portfolio in the e-mobility market (Singh, 2010)

With the upcoming market, a 2nd life market also emerges. Battery technology is advancing rapidly and new technologies improve energy storage, discharge rates, recharge life cycles and charging rates. This means that many batteries will be produced in the next 10 to 15 years until the most efficient and effective battery configuration has been realized. 2nd life batteries may find use in less energy demanding purposes, refurbishing and, more importantly, recycling. As discussed in paragraph 2.5.1, a lithium-ion battery can be recycled with minimal environmental impact and more than 95% of the battery materials can be recovered and reused. This will create a vast 2nd life market.

With the broad introduction of smartphones and tablet computers, software providers have shown huge interests in producing not only billing systems, but will also contribute to the market by developing other applications for the e-mobility market. To enhance mobility for vehicles sharing, vehicle access and security, entertainment, and navigation, automotive applications should be developed in the coming years.

Some examples are applications for:

- Road assistance
- Vehicle locating
- Car sharing and vehicle access
- Charging specification
- Car pooling
- Vehicle health and servicing status
- Charging station locator
- Theft and security
- 3D navigation with video support
- Car sharing, choosing, reserving and locating cars (for fleet purposes)

The e-mobility market can thus potentially create many job opportunities. The Department of Trade and Industry of the Republic of South Africa stated in its Industrial Policy Action Plan (IPAP) 2011/12 – 2013/14 economic sector and employment cluster, that an estimated 160 000 direct jobs will be created in the industry in the next ten years. Furthermore, investment levels exceeding R20 billion are expected to take place in the next four years, with an expected further annual R3 billion for the following six years. Greater localisation of component manufactures will lead to an improvement in the trade balance. The creation of 160 000 direct jobs compared to 4 538 000 unemployed persons between the age of 15 and 64 is 3,53% of the total unemployment rate in South Africa after Q2 2011 (Stanlib, 2011).

3 CHAPTER THREE - RECENT PROGRESS WORLDWIDE

3.1 Market forecasts and governmental incentives

In this chapter the electric vehicle market, forecasts from manufacturers and consultant groups, proposed and introduced governmental incentives, and uptake rates are discussed for emerging markets in the United States of America, Europa, Asia and South Africa.

Competition is increasing fast among car manufacturers, and many accredited and new manufacturers are producing PEH and other sorts of EVs for the possible future ways of electronic transportation. For now, production of the announced vehicles that are to be produced in the coming years can change rapidly due to market conditions. While many manufacturers are planning on producing PEVs in the foreseeable future, only a couple actually scheduled production for 2011/2012. A survey to identify the top 10 manufactures of ICE vehicle production worldwide for the year 2010 has been carried out by The International Organization of Motor Vehicle Manufacturer, also known as the “Organisation Internationale des Constructeurs d’automobiles” (OICA), that was founded in Paris in 1919 (OICA, 2010). The results are displayed in Table 5. It is interesting to see that, from the top 10 car manufacturers, only two have a 100% electric vehicle commercially available, namely, the Nissan Leaf, and the Renault Z.E. models. All other manufactures are still developing, or are in the process of testing prototypes. Table 6 shows PEVs availability or scheduled production of these top 10 manufacturers.

Table 5: OICA World ranking of manufacturers in 2010 (OICA, 2010)

Rank	Group	Total
1	Toyota	8,557,351
2	GM	8,476,192
3	Volkswagen	7,341,065
4	Hyundai	5,764,918
5	Ford	4,988,031
6	Nissan	3,982,162
7	Honda	3,643,067
8	PSA	3,605,524
9	Suzuki	2,892,945
10	Renault	2,716,286

Table 6: PEVs available or scheduled from the top 10 manufacturers (Graham, Messer, Hartman, & Lane, 2011)

Group	Models	Timeline
Toyota Partner project with Tesla[1, 2]	RAV4 EV	2012
GM	Unknown	Unknown
Volkswagen[3,4,5]	Audi e-tron, A1 E-Tron VW E-golf twin drive VW UP!	Audi e-tron, A1 E-Tron 2012 VW E-golf Testing in U.S. 2012 2013
Hyundai[6]	Unknown	Hyundai Elantra concept car 2012
Ford[7]	Focus BEV	In serial production 2011
Nissan[8]	Leaf, NV200, Infiniti EV	Leaf In serial production
Honda[9, 10]	First fit	Production in 2013 Fleet test in Torrance, California for Google and Stanford University 2012
PSA[11, 12]	Peugeot iOn Citroen C-Zero	2011 2012
Suzuki[13]	Concept Q electric car	Unknown
Renault[14]	Twizy ZOE Fluence Z.E. Kangaroo Maxi Z.E.	Serial production 2012

[1] http://www.cars-electric.com/electric-cars-2012/
[2] http://reviews.cnet.com/8301-31166_7-20023294-271.html
[3] http://www.digitaltrends.com/cars/volkswagen-launches-electric-car-pilot-program/
[4] A06 Plug-in Electric Vehicles- A Practical Plan for Progress
[5]http://www.treehugger.com/cars/vw-announces-electric-car-for-2013-warns-against-electro-hype.html
[6] http://blogs.cars.com/kickingtires/2012/01/hyundai-elantra-electric-at-the-2012-detroit-auto-show.html
[7] A06 Plug-in Electric Vehicles- A Practical Plan for Progress
[8] http://gm-volt.com/2010/12/11/first-nissan-leaf-delivered-today/
[9] http://automobiles.honda.com/fit-ev/
[10] http://www.autoblog.com/2012/01/24/honda-delivers-first-fit-ev-to-city-of-torrance/
[11] http://www.peugeot.com/en/products/cars/ion.aspx
[12] http://www.electric.citroen.com
[13]http://www.motorauthority.com/news/1068386_suzuki-bringing-trio-of-city-car-concepts-to-tokyo-including-new-regina
[14] http://www.renault-ze.com/en-gb/z.e.-range-1932.html

There are still many barriers and uncertainties to overcome in order to successfully deploy PEVs into the market. The biggest concerns of vehicle manufacturers are the battery technology, the lack of infrastructure, and charging standards. Test cases, demonstration projects, and fleet test results should provide more insights into these concerns and could possibly speed up the EV market by driving down the barriers for consumers to embrace a new way of transportation. Market outlooks of different countries are described in this chapter.

3.1.1 USA

The United States president, Barack Obama, called for the introduction of 1 million EVs on the road before 2015, in his state of the union address in November 2011, in order to dramatically reduce oil dependency and to ensure a leading role in the growing electric vehicle manufacturing industry. To achieve this, President Obama has proposed a new effort that supports advanced technology vehicle adoption through improvements to tax credits in current law, investments in R&D, and competitive programs to encourage communities to invest in infrastructure supporting these vehicles (DOE U.S., 2011).

The global financial crisis that struck in 2008 had a big impact on the sales numbers of light duty vehicles (LDV) in the USA but, fortunately, sales have grown from 10 million in 2009 to 12 million in 2010, while still recovering from the recession. HEVs only make up 3% of all sold light duty vehicles and, in order to introduce 1 million EVs by 2015, EV sales will need to average just under 1.7% of sales through 2015, assuming sales of 12 million light duty vehicles per year (DOE U.S., 2011). According to the DOE, the market for electric vehicles is expected to increase. GM and Nissan are the two leading manufacturers. GM introduced its extended range vehicle, called the Volt, in 2010 and has announced that it will build 15 000 Volts in 2011, 45 000 in 2012, and, allegedly, there are plans to increase the production to 120 000 by 2012. The Nissan Leaf was first introduced in the United States in 2010 and scheduled production for 25 000 Leafs in 2011 and another 25 000 in 2012. Table 7 shows an overview of planned and available PEVs in the United States.

Table 7: Plans for PEVs in the U.S. Market

Car Company	PHEV	BEV	Models	Timeline	Planned production Output
Audi	Yes	Yes	e-tron, A1 e-tron	2012	"Limited"; "small build"
BMW	No	Yes	MINI-E, Active-E, Megacity	MINI-E and Active-E in pilot lease programs currently Megacity: 2013	Unknown
BYD	Yes	Yes	E6, S6DM	E6: 2012 (pilot testing in L.A. began in 2010)	Unknown
CODA Automotive	No	Yes	CODA Sedan	2012	14,000 cars within 12 months of debut
Chrysler-Fiat	No	Yes	Fiat 500	2012	Unknown
Daimler	No	Yes	Smart ED Fortwo	2012	1,500 globally in 2011, series production in 2012
Fisker	Yes	No	Karma, Nina	Karma: spring 2011 Nina:	Karma: 15,000

Automotive				mid-2012	annually
Ford	Yes	Yes	Focus BEV, Transit Connect Electric, unnamed PHEV	Transit Connect Electric: began in late 201010 Focus BEV: 2011 Unnamed PHEV: 2012	Transit Connect Electric: 600-700 annually beginning in April 201112 Focus BEV: 5,000-10,000 units annually
GM	Yes	No	Volt	In serial production	2011: 10-15,000 units 2012: up to 60,000 units
Honda	Yes	Yes	Unknown	2012	Unknown
Mitsubishi	Yes	Yes	iMiEV, PX-MiEV	i-MiEV: 2011 PX-MiEV: 2013	Unknown
Navistar	No	Yes	eStar	In serial production	Unknown
Nissan	No	Yes	LEAF, NV200, Infiniti EV	LEAF: In serial production	LEAF: 500,000/year globally by 2012
Smith Electric	No	Yes	Newton	In serial production	Capacity of 30 per week as of 2008
Tesla	No	Yes	Roadster, Model S	Roadster: in serial production Model S: 2012	Roadster: 1,200 annually Model S: 20,000 annually
TH!NK	No	Yes	City EV	Current fleet sales underway, retail serial production by summer 2012	300 in U.S. by early 2011
Toyota	Yes	Yes	Prius PHEV, Unnamed BEV	2012	Prius PHEV: “tens of thousands” annually
Volkswagen	Yes	Yes	Golf Twin Drive, Golf blue-e-motion/E-Up, all-electric Jetta	Golf Twin Drive: test fleet in 2012 Full production of all planned PEVs: 2013	Unknown
ZAP	No	Yes	Alias	Unknown	Unknown, currently taking orders for limited edition version
Data adapted from (Graham, Messer, Hartman, & Lane, 2011)					

Table 8 shows the estimated US supply of electric vehicles from 2011 through 2015, and only describes vehicles that are manufactured by American manufacturers or PEV’s that have been (partially) manufactured in the U.S, such as the Nissan Leaf. Both the data and table are adapted from the Department of Energy’s EV status report of February 2011 (DOE U.S., 2011).

Table 8: estimated U.S. Supply of Electric Vehicles from 2011 through 2015

Estimated U.S. Supply of Electric Vehicles from 2011 through 2015

Manufacturer and Model	2011	2012	2013	2014	2015	Total
Fisker Karma PHEV	1,000	5,000	10,000	10,000	10,000	36,000
Fisker Nina PHEV		5,000	40,000	75,000	75,000	195,000
Ford Focus EV		10,000	20,000	20,000	20,000	70,000
Ford Transit Connect EV	400	800	1,000	1,000	1,000	4,200
GM Chevrolet Volt	15,000	120,000	120,000	120,000	120,000	505,000
Navistar eStar EV (truck)	200	800	1,000	1,000	1,000	4,000
Nissan LEAF EV	25,000	25,000	50,000	100,000	100,000	300,000
Smith Electric Vehicles Newton EV (truck)	1,000	1,000	1,000	1,000	1,000	5,000
Tesla Motors Model S EV		5,000	10,000	20,000	20,000	55,000
Tesla Motors Roadster EV	1,000					1,000
Think City EV	2,000	5,000	10,000	20,000	20,000	57,000
Cumulative Total						1,222,200

To support the introduction of 1 million EVs by 2015, the Unites States have initiated a new policy and incentives to stimulate EV adoption.

3.1.1.1 Incentives and federal policy

Initiatives and government policies are necessary to encourage the introduction of EVs. With policies in place, the industry can achieve the planned production, encourage investment in manufacturing facilities, and create demonstration pilots. Incentives should promote adoption and driver demand.

The US announced in their Recovery Act that they would make investments to build domestic manufacturing capacity and secure their perceived position. They believe to be a global leader in advanced lithium-ion battery technology. This investment includes:

- $ 2.4 billion in loans to three of the world's first EV factories in Tennessee, Delaware and California; and
- $ 2 billion in grants to support 30 factories that produce batteries, motors and other EV components. These grants are enabling companies to build the capacity to produce 50 000 EV batteries annually by the end of 2011 and 500 000 EV batteries annually by December 2014 (DOE U.S., 2011).

The funds from the Recovery Act will also support the launch of demonstration projects for electric vehicles and will include almost 13 000 vehicles and more than 22 000 electric charging points in over 20 cities across the United States. $ 400 million dollars has been invested by the public sector and companies are matching this dollar for dollar (DOE U.S., 2011).

The Recovery Act established tax credits for purchasing electric vehicles. A newly purchased EV will comply with a tax credit between $ 2,500 and $ 7,500, depending on the battery capacity. Conversion kits to retrofit ICE powered vehicles with EV capability can expect a tax credit of $ 4,000 maximum per vehicle.

New proposals and initiatives to support advanced technology vehicles have been announced by the US president and are as follows:

- Transform the excising tax credit of $ 7,500 into a rebate;
- Enhance R&D investments in electric drive, batteries and energy storage technology; and
- Reward communities that invest in EV infrastructure through competitive grants.

The budget proposes to expand funding for vehicle technologies by almost 90% to nearly $590 million. In order to stimulate EV investments, technology up take, reduce barriers, and developing a charging infrastructure, the Department of Energy has begun a program to reward communities who become early adapters of a new transportation system. Up to 30 communities across the country can receive grants of up to $ 10 million each on the basis of their ability to demonstrate concrete reforms and use the funds to help catalyse electric vehicle deployment (The White house, 2011).

According to data compiled by Bloomberg in April 2012, "Electric-drive vehicles, including hybrids, plug-in models and pure battery-powered cars, were the fastest-growing segment in the U.S. auto market in the first quarter. Sales of those models rose 49% to 117,182 vehicles in the first quarter, from 78,527 a year earlier" (Naughton & Ohnsman, 2012).

3.1.2 Europe

The European Green Cars Initiative (EGCI) is a research and innovation measure that is included in the European Economy Recovery Plan. The EGCI is a so-called private public artnership (PPP), and was announced by the European Commission on 26 November 2008. The EGCI provides funding for research, industrial innovation and the production of cars. The European Community, the European Investment Bank, industry and Member States fund the EGCI, which is worth a total amount of € 5 billion. The Seventh Framework Programme for Research (FP 7) and the private sector subsidize € 1 billion. The other € 4 billion are obtained through loans from the European Investment Bank. On March 12 2009, the European Investment Bank approved € 3 billion in loans for European car and truck manufacturers (BMW, Daimler, Fiat, PSA Peugeot-Citroen, Renault, Volvo Cars, Scania and Volvo Trucks) (Slater, Dolman, Taylor, & Trichakis, 2009).

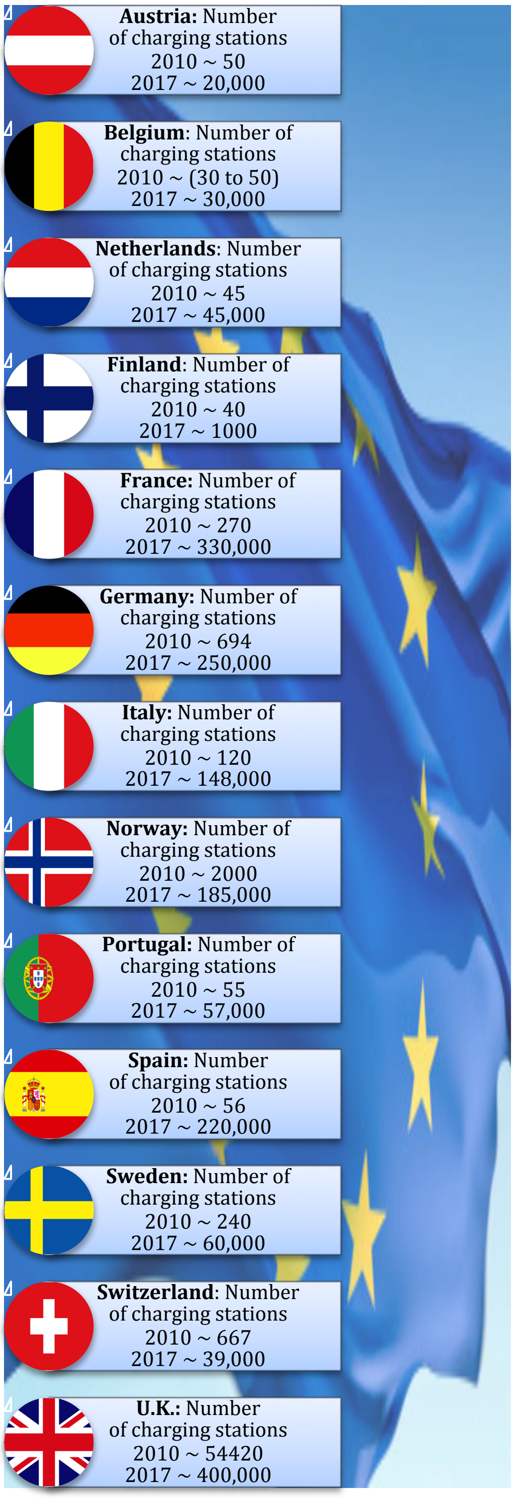


Figure 20: Charging stations in the EU

According to the Annual Growth Survey 2012 of the European Commission, the deployment of electric vehicles has major market potential, growing from 100 000 today to 1 million hybrid vehicles by 2020, whilst the fully-electric vehicle market is expected to reach 750 000 units by 2020 (European Commission, 2012).

3.1.2.1 Incentives by country

The list below describes incentives granted per member state of the European Union for the purchase and use of electric vehicles, including plug in and conventional hybrids. The data is acquired from the ACEA (Association des Constructeurs Européens d'Automobiles), better known as European Automobile Manufacturers Association, Tax Guide of April 2012. Note that throughout this list the term "electric vehicles" refers to vehicles that are exclusively powered by an electric motor (ACEA, 2012). The announced incentives relate to ownership of the vehicle. Incentives regarding installation of charging equipment and other necessities of charging infrastructures have not been established yet.

Austria	Electric vehicles are exempt from fuel consumption tax and from monthly vehicle tax. Hybrid vehicles and other alternative fuel vehicles benefit from an additional bonus under the fuel consumption tax. This fuel consumption tax (Normverbrauchsabsage or NoVA), is levied upon the first registration of a passenger car. Under a bonus-malus system, cars emitting less than 120 g/km receive a maximum bonus of € 300. Alternative fuel vehicles, including hybrid vehicles, attract an additional maximum bonus of € 500. This bonus regime is valid from 1 July 2008 until 31 August 2012.
Belgium	Private persons who purchase a passenger car that is powered exclusively by an electric motor receive a personal income tax reduction of 30% of the purchase price (with a maximum of € 9,510). Vehicles that do not qualify for the 30% income tax reduction may benefit from the Eco-bonus in Wallonia (€ 500–3,500 for cars emitting less than 80 g/km). Electric vehicles are exempt from registration tax in Flanders. They pay the lowest rate of tax under the registration tax (€ 61.50) in the Brussels and Walloon regions, and under the annual circulation tax (€ 73.79) in all three regions. The deductibility rate for expenses related to the purchase and use of company cars is 120% for zero-emissions vehicles and 100% for vehicles emitting between 1 and 60 g/km of CO 2. Above 60 g/km, the deductibility rate decreases gradually from 90% to 50%.

Czech Republic	Electric, hybrid and other alternative fuel vehicles are exempt from the road tax (this tax applies to cars used for business purposes only).
Denmark	Electric vehicles weighing less than 2,000 kg are exempt from the registration tax. This exemption does not apply to hybrid vehicles.
Germany	Electric vehicles are exempt from the annual circulation tax for a period of five years from the date of their first registration.
France	Vehicles emitting 50 g/km or less of CO_2 benefit from a premium of maximum € 5,000 under a bonus-malus scheme. For such vehicles, the amount of the incentive cannot exceed 20% of the vehicle purchase price including VAT, increased with the cost of the battery if this is rented. Hybrid vehicles emitting 110 g/km or less of CO_2 benefit from a premium of € 2,000. Electric vehicles are exempt from company car tax. Hybrid vehicles emitting less than 110 g/km are exempt during the first two years after registration.
Finland	Electric vehicles pay the minimum rate (5%) of the CO_2 based registration tax.
Ireland	Electric vehicles are exempt from the registration tax, VRT, up to a maximum of € 5,000. Plug-in hybrids benefit from VRT relief of a maximum of € 2,500. Conventional hybrid vehicles and other flexible fuel vehicles benefit from VRT relief of a maximum of € 1,500.
Italy	Electric vehicles are exempt from the annual circulation tax (ownership tax) for a period of five years from the date of their first registration. After this five-year period, they benefit from a 75% reduction of the tax rate applied to equivalent petrol vehicles in many regions.
Luxembourg	Purchasers of electric vehicles (or other vehicles emitting 60 g/km or less of CO_2) receive a premium of € 5,000 (PRIMe CAR-e) until 31 December 2012. The purchaser must have concluded an agreement to buy electricity from renewable energy sources in order to obtain the

premium.

Netherlands	Electric vehicles are exempt from the registration tax, BPM, and from annual circulation tax. Other vehicles, including hybrid vehicles, are also exempt from these taxes if they emit less than 95 g/km (diesel) or less than 110 g/km (petrol) respectively.
Norway	No VAT (25 % of retail price). Lower annual registration fee. Exempt from road charges, access to free parking and bus lanes.
Portugal	Electric vehicles are exempt from the registration tax, ISV, and from the annual circulation tax. Hybrid vehicles benefit from a 50% reduction of the registration tax.
Romania	Electric and hybrid vehicles are exempt from the special pollution tax (registration tax).
Spain	Various regional governments (Aragon, Asturias, Baleares, Madrid, Navarra, Valencia, Castilla la Mancha, Murcia, Castilla y Léon, Cantabria, Catalunya, Galicia, Pais Vasco, Extremadura) grant incentives of € 2,000 to € 7,000 for the purchase of electric, hybrid, fuel cell, compressed natural gas (CNG) and liquefied petroleum gas (LPG) vehicles. In Andalucia, the incentive is maximum 70% of the investment.
Sweden	Electric vehicles with an energy consumption of 37 kWh per 100 km or less, and hybrid vehicles with CO_2 emissions of 120 g/km or less are exempt from the annual circulation tax for a period of five years from the date of their first registration. For electric and plug-in hybrid vehicles, the taxable value of the car for the purposes of calculating the benefit in kind of a company car under personal income tax is reduced by 40% compared with the corresponding or comparable petrol or diesel car. The maximum reduction of the taxable value is SEK 16,000 (€ 1750) per year. From 1 January 2012, a so called “Super green car premium” (Supermiljöbilspremie) of SEK 40,000 (€ 4375) has been

	introduced for the purchase of a new cars with CO_2 emissions of maximum 50 g/km. The premium is applied to the purchase by private persons and companies. For companies purchasing a super green car, the premium is calculated as 35% of the price difference between the super green car and a corresponding petrol/diesel car, with a maximum of SEK 40,000.
United Kingdom	Purchasers of electric vehicles and plug-in hybrid vehicles with CO_2 emissions below 75 g/km receive a premium of £ 5,000 (maximum) or 25% of the value of a new car or £ 8,000 (maximum) or 20% of the value of a new LCV meeting eligibility criteria (for example, minimum range 70 miles for electric vehicles, 10 miles electric range for plug-in hybrid vehicles). Electric vehicles are exempt from the annual circulation tax. This tax is based on CO_2 emissions and all vehicles with emissions below 100 g/km are exempt from it. Electric cars are exempt from company car tax until April 2015 and electric vans are exempt from the van benefit charge until that date too.

Table 9 illustrates an overview of the announced EV and PHEV sales targets from European member states for 2020.

Table 9: Announced European EV and PHEV sales targets

Country	Target	Announcement / Report date
Denmark	2020: 200,000	n.a.
France	2020: 2,000,000	March 2011
Germany	2012: 1,000,000	March 2011
Ireland	2020: 230,000 2030: 40% market share	1 October 2009
Netherlands	2015: 20,000 stock 2020: 200,000 stock	May 2011
Spain	2020: 2,500,000	March 2011
Sweden	2020: 600,000	March 2011
Switzerland	2020: 145,000	July 2009

United Kingdom	2020: 1,200,000 stock EVs + 350,000 stock PHEVs 2030: 3,300,000 stock EVs + 7,900,000 stock PHEVs	October 2008
Source: Data adapted from International energy Agency _technology roadmap; electric and plug-in hybrid electric vehicles. Updated June 2011 (IEA, 2011)		

Table 10 contains data adapted from a Jato report and is based on the following assumptions (Jato, 2011);

- Calculations are based on the maximum subsidy allowable per market (Belgium for instance offers a reduction on initial vehicle price up to € 9,510);
- Company car purchases are excluded and may attract different subsidies;
- All calculations are based on 'typical' EV ownership of five years although on-going subsidies in kind (such as road tax reductions) may continue to accrue;
- No calculations have been made to allow for inflation or for increases to road/circulation taxes;
- Calculations have focused the financial benefit predicted at point of purchase;
- Local market tax calculations are based (where appropriate) on the Volkswagen Golf 1.4 TSI 122bhp or market equivalent;
- The € equivalent is the combination of tax deductions and cash (where applicable) over a five-year period of new car ownership; and
- The calculations do not factor in the true cost of EVs in each market, i.e., despite the large amount of tax savings in Denmark, Danish EVs could be more expensive than in other markets.

Table 10: Incentives per European member state expressed in Euro.

Country	Incentives (€) August 2011	Country	Incentives (€) August 2011
Austria	2,571	Luxembourg	-
Belgium	10,907	Netherlands	4,936
Czech Republic	271	Norway	17,524
Denmark	20,588*	Portugal	9,442
Germany	380	Romania	3,700
France	5,000	Spain	6,500
Finland	-	Switzerland	0
Ireland	5,000	Sweden	470
Italy	1,200	UK	6,400
Source: Jato press release of 26 September 2011; Incentives fail to stimulate European electric vehicles sales. (Jato, 2011) * See appendix A4 for a example of registration tax calculation in Denmark			

3.1.3 Japan

The Japanese government set a target in 1998 for the introduction of clean air vehicles by 2010, in order to comply with the targeted CO_2 emissions reduction based on the Kyoto protocol. The target for clean energy vehicles was set to achieve 3,65 million vehicles, of which about 100 000 EVs and 2 000 000 PHEVs, in the total vehicle fleet by 2010 (Hazeldine, Kollamthodi, Branningan, Morris, & Deller, 2009). In 2010, Japan produced 9,628,920 vehicles in total (OICA, 2010). How much of the total produced cars were clean air vehicles has not been specified.

3.1.3.1 Incentives

Hazeldine, Kollamthodi, Branningan, Morris, and Deller (2009), reported that a budget of about USD 100 million per year was invested in this programme. Incentives have been introduced to help ensure that these targets are reached. These include:

- Electric and hybrid electric vehicles can receive a purchase subsidy of up to 50% of the incremental cost of a vehicle;
- Subsidy for the establishment of clean energy vehicle refuelling facilities;
- Funding demonstration for low-pollution vehicles including car-sharing and station car;
- Discount on the automobile tax; and
- Business tax credit – purchase of clean energy vehicles for business use and establishment of fuelling facilities for CNG and methanol vehicles.

In order to acquire the proposed 38% clean energy vehicles of all vehicles manufactured in Japan, the Japanese government has decided to continue the present tax breaks until 2015. According to Sprei & Bauner (2011), hybrid vehicles will have an acquisition reduction from 2,2% to 5% which implies a reduction of about € 400. Also, there will be an annual tax reduction for EVs and PHEVs (a Toyota Prius owner will save about € 100). Sprei & Bauner (2011) have reported the following:

- There will be a tax break and the possibility of loans for corporate fleets;
- The purchase incentive for “eco-friendly” vehicles that were suspended in September 2010 will also be resumed for one year; and

- An earlier subsidy of several thousand Euros has now been reduced. The amount is calculated on the basis of vehicle weight and environmental performance, and would, for a Prius, amount to around € 1400.

It has been stated that the Japanese Government offers incentives of up to 1 390 000 Yen, or USD 16,000, off the retail price of electric vehicles, and reductions in road tax and registration fees (Hazeldine, Kollamthodi, Branningan, Morris, & Deller, 2009).

3.1.4 China

China is a leader in manufacturing electric and commercial vehicles. According to The Economist (2009), there are already twenty million electric vehicles in the form of two-wheeled electric bikes and scooters on Chinese roads. Although China is leading when it comes to EV production, it's struggling with infrastructural deployment but strives to be a frontrunner in this aspect to. In the electric vehicle charging infrastructure 2011-2021 report from IDTechEX, it's said that the largest power company in China, the State Grid Corporation of China (SGCC), plans to build 75 public charging stations in 2010 to support the country's "Energy-efficient and New-energy Vehicle Pilot Program". 6 209 AC charging spots and some battery replacement stations are projected.
Since 2006, the SGCC has equipped itself with 101 electric vehicles and 30 pilot charging stations and cooperated with the Beijing municipal government in designing 7 electric bus lines and manufacturing 58 electric buses. Harrop & Zervos (2011) also reported that Beijing will build both fast charging and slow charging stations in a bid to promote the use of electric vehicles, and that a spokesperson for the Beijing Municipal Science & Technology Commission, Zhu Shilong, gave details about the city plans to build 36 000 slow charging stations, 100 fast charging stations, 2 battery recycling stations, and 10 maintenance service stations. Beijing has, so far, invested 20 million Yuan (USD 3 million) in R&D of new energy vehicles, and there will be 30 000 electric passenger cars in operation by 2012, including 23 000 electric vehicles and 7 000 plug-in hybrid vehicles (Harrop & Zervos, 2011).

According to government officials and Chinese auto executives, China is expected to raise its annual production capacity to 500 000 plug-in hybrid or all electric cars and buses by the end of 2011 (Bradsher, 2009). The Chinese government will invest more than 100 billion Yuan (USD 14.8 billion) to subsidise its fairly new and developing environmentally friendly car industry over the next 10 years (Ciarcia, 2011). The

Chinese government announced that five cities, including Shenzhen, Shanghai, and Beijing, would be hosting demonstration projects to accelerate installation of charging equipment and to make private ownership of vehicles viable.

3.1.4.1 Incentives

A draft regulation released by China's state council that has been posted on its website says that full electric vehicles will be exempt from annual taxes from the 1st of January 2012 and onwards. The draft also states that pure electric, fuel cell and plug-in hybrid vehicles are tax exempt and other hybrid vehicles are eligible for a 50% cut.

Tianyang (2011) and Yingpu & Wei (2012) reported that the government began offering a maximum subsidy of 60,000 Yuan (USD 9,500) to users of pure-electric cars, and 50,000 Yuan to users of plug-in hybrids in five pilot cities in June last year. Local governments in Shenzhen and Shanghai provide additional subsidies for new-energy vehicles. The central government also offers a subsidy of 3,000 Yuan to buyers of cars with engines smaller than 1.6 litres. Buyers of hybrid cars, which run on a combination of batteries and conventional engines, are entitled to an incentive of 5,000 Yuan ($790) per vehicle, while a rebate of up to 60,000 Yuan on the purchase price is offered to buyers of battery-driven cars. Not only does the Chinese government stimulate EV adoption by incentives, vehicle manufactures are offering buyers of their electric vehicles free maintenance and other personalized services.

A recent survey conducted by the China Association of Automobile Manufactures showed that 8 159 hybrid and electric cars were sold throughout the nation in 2011. All together, there are more than 10,000 green cars on Chinese roads. (Yingpu & Wei, 2012).

Despite government and vehicle manufactures incentives, the proposed target of putting 500 000 EVs on the road by 2011 could not be accomplished. Reasons for not reaching the target are unknown. The deadline has been extended to 2015.

3.1.5 South Africa

According to the draft paper on South African electrical vehicle industry strategy from the DTI, the transportation sector accounts for 30% of the CO_2 emissions in the industrialized economies of the OECD (Organization for Economic Cooperation and Development) and about 20% worldwide. In order to reduce the CO_2 emissions, South Africa's vision is "to produce 120 000 electric vehicles of the envisioned 1,2 million in South Africa by 2020 for the domestic and export markets, thereby establishing a well-developed green technology sector leading to increased investments, job opportunities and human capacity building" (DTI, 2011). South Africa and its electrification of transportation plans are still in an infant state and no incentives have been agreed upon, though there are a number of proposals.

3.1.5.1 Incentives

In order to encourage the purchase of EVs in South Africa, the DTI is working on a proposal that shall include tax benefits, personal income tax rebates, reduction of VAT on retail selling price, and vehicle registration costs. The key action plans of the draft paper on South African electrical vehicle industry strategy are as follows:

- 2011/12 Q4: Tax benefit proposals investigated and discussed with NT;
- 2012/13 Q1: Draft tax benefits proposal;
- 2012/13 Q3: Key stakeholder consultation/general public comments process; and
- 2013/14 Q2: Draft tax rebate proposal with the public's inputs finalised final draft sent to NT.

For now, no incentives are in place yet except for the new "green" tax. Owners of an EV with CO_2 emissions below 120 g/km (current National treasury target) qualify for a tax rebate. Emission control regulation and taxes on new non-EV sales should serve as encouragement to guide consumers to opt for greener mobility options. The incremental tax collected could be utilized to fund additional support incentives for the sector (DTI, 2011). For each extra gram of CO_2/km emitted, the car's price increases by R 85.50 (R 75 plus VAT). According to the National Association of Automobile Manufacturers of South Africa (NAAMSA), this will bring about an average price increase of 2.5% (Wyk, 2010). Table 11 shows South Africa's CO_2 vehicle emission tax (Clutch'd, 2010).

Table 11: South Africa's CO_2 vehicle emissions tax

CO_2 emissions g/km	Average CO_2 emissions g/km	Number of vehicles, 12 months	% of vehicles 12 months	CO_2 emissions above threshold: g/km > 120	Tax @ R75 per g/km	Average price	Average tax rate
Below 120	110	342	0.2%	–	–	R 177 000	0.0%
	120	493	0.2%	–	–	R 170 000	0.0%
	130	10 904	4.9%	10	750	R 121 000	0.6%
	140	15 856	7.2%	20	1 500	R 164 000	0.9%
	150	20 794	9.4%	30	2 250	R 169 000	1.3%
	160	21 694	9.8%	40	3 000	R 181 000	1.7%
	170	33 552	15.2%	50	3 750	R 166 000	2.3%
	180	46 664	21.1%	60	4 500	R 164 000	2.7%
	190	24 224	11.0%	70	5 250	R 244 000	2.2%
	200	10 183	4.6%	80	6 000	R 293 000	2.0%
	250	22 928	10.4%	130	9 750	R 391 000	2.5%
	300	8 083	3.7%	180	13 500	R 552 000	2.4%
	350	4 161	1.9%	230	17 250	R 551 000	3.1%
	400	778	0.4%	280	21 000	R 947 000	2.2%
Above 400	450	25	0.01%	330	24 750	R 606 000	4.1%
Average/Total	**178**	**220 681**	**100.0%**	**58**	**4 350**	**R 227 000**	**1.9%**

The DTI's draft paper also describes investment supports for the manufacturers of electric vehicles and components. The Amendment of the Automotive Investment Scheme (AIS) of the Automotive Production and Development Program (APDP) is to enable EVs and related components to participate in the scheme through the reduction of qualifying annual 50,000 units per plant quota to 5,000 units annual per plant. The AIS is an incentive designed to grow and develop the automotive sector by investments that will increase plant production volumes and/or strengthen the automotive value chain. It provides for a taxable cash grant of 20% of the value of qualifying investment in productive assets by the DTI, as well as an additional taxable cash grant of 5% or 10% for so-called strategic projects (DTI, 2011).

The DTI is planning on researching and benchmarking global available tax incentives models in the same way as it has done with the introduction of carbon taxes in 2010.

3.1.5.2 EV progress and model availability

Although there is no public charging infrastructure realized yet, electric vehicles are slowly being introduced into the South African market. On December 16th of 2011, Wesbank stated in a press announcement that 2011 sales of hybrid cars made up less than 1% of the total passenger vehicles sales in South Africa (Wesbank, 2011). With the introduction of more hybrid car brands, different models, raised concern about the environmental impact of conventional cars, and South Africa's target to reduce greenhouse gas emission with 34% by 2012 (DTI, 2011), the hybrid and EV market in South Africa is striving forwards. Table 12 shows the commercially available hybrid cars, their retail price and CO_2 emission rate in South Africa.

Table 12: Commercially available hybrid cars in the RSA

Brand	Model	CO_2 emission g/km	Retail price in R (incl CO_2 tax and VAT)
Toyota[1]	Prius 1.8 l advanced	94	342,800.00
	Prius exclusive	115	389,600.00
Lexus[2]	CT 200h S	94	355,400.00
	CT 200h EX	94	401,000.00
	CT 200h F-sport	94	412,500.00
Lexus	GS450h	180	769,500.00
Lexus	RX450h XE	148	766,000.00
	RX450h LXE	148	805,100.00
Lexus	LS600h L	219	1,679,900.00
Honda[3]	Insight 1.3 hybrid	103	272,500.00
	Jazz hybrid	105	247,100.00
	CR-Z 1.5 hybrid	117	305,898.00

All emission figures are depending on drive style and servicing history of vehicles.
Sources: [1] http://www.toyota.co.za/VehicleRange.aspx?vehicleRangeId=16
[2] http://www.lexus.co.za/model/price-and-specifications
[3] http://www.honda.co.za/main.aspx? ID=656

Note that Table 12 doesn't reflect any full battery powered electric vehicles. This is due to the fact that manufacturers haven't released any full EVs in the country yet but this is to change in due course. The Renault Fluence F.E. and Twizy were shown at COP17 in Durban during December 2011 as part of a demonstration plan, and Renault SA says it is ready to bring electric cars to SA but that it will not do so until adequate infrastructure is in place (Woosey, 2012).

According to Mike Whitfield, managing director of Nissan South Africa, the Nissan Leaf is expected to be available in 2013 but only when government has its electric vehicle policy in place. This policy will need to include details on charging infrastructure and incentives such as possible duty rebates on electric vehicles (Venter, 2011).

BMW South Africa is also focussing on the South African e-mobility market and announced it will conduct a local trial study of the Mini E during the first quarter of 2012 with the intention of launching the vehicle locally at a later stage. No results have been published so far.

3.1.5.3 Optimal Energy's Joule

Optimal Energy is a privately owned South African EV manufacturer based in Cape Town and the Joule (see Figures 21 and 22) is it's first, and so far only, model to date. The locally developed EV focuses on urban mobility, export, government, corporate and passenger fleets. The manufacturing plant that is to be built in East London's industrial zone has a nominal capacity of 50 000 vehicles per year and can be scaled up to a maximum of 90 000 vehicles per year. Production and market introduction of the Joule is scheduled for late 2013 and the first vehicles should be available in 2015[2]. In order to do so, a total investment of approximately R 9 billion is required to start up production by 2015[3]. R 3,5 billion for the industrializing of the Joule, establishment of a plant to build the car for local and export markets requiring another R3.5 billion and R2 billion is envisaged to be required for retail and after-sales service (Venter, 2012).

Figure 21: The SA produced Joule prototype photographed from the back

Figure 22: The SA produced Joule prototype photographed from the front

2 CEO Kobus Meiring of Optimal Energy; presentation for the Institution of Engineering and Technology (IET), 2010

3 Electric vehicles IPAP 2 Key action program 7 presentation by Optimal Energy's CEO Kobus Meiring, 2011

Recent developments forced Optimal Energy to abandon its core idea of building an EV for local and export market due to lack of government funding and not being able to establish a partnership with either an automotive original equipment manufacturer or a "big player" in the industry as advised by the Industrial Development Corporation (IDC). According to Smyth (2012), CEO Kobus Meiring said that, “Due to the financial constraints on the next phase of the P50k (Joule) strategy, the company’s focus in the medium term will move to the development of an electric bus (e-Bus)” In that same interview, Mr Meiring mentioned that a total of R 300 million has been spent to date and that the IDC and the Department of Science and Technology hold, respectively, 50% and 30% off the stakes in Optimal Energy. The rest of the shares are in the hands of private investors.

Optimal Energy was waiting for government support in the form of investments and commitment in order to be able to commercialize the vehicle, but all hope seems to have faded.

This is, however, in conflict with the draft position paper on EV industry strategy by the DTI who concluded in their report that “it is important that South Africa ensures a conductive investment environment to ensure the local manufacturing of EVs. The most suitable mechanism to ensure the highest potential internal beneficiation and value addition, is in the support of commercialization of South Africa’s own EV, the Joule” (DTI, 2011). Government investment and commitment stayed out to long for Optimal Energy to keep the company financially viable while pursuing their initial core strategy of producing electric vehicles.

3.1.6 Summary

The governmental incentives, investments and budgets that were described in paragraph 3.1 are very different per country.

The USA, for instance, announced it would invest $ 4,4 billion and proposed to transform the tax credit for a newly purchased EV ($ 2,500-$ 7,500) into a rebate. Furthermore, they are investing more than $ 400 million dollars in demonstration projects for electric vehicles and will include almost 13 000 vehicles and more than 22 000 electric charging points in over 20 cities across the United States.

Europe, however, plans to invest approximately $ 6,2 billion and grants incentives ranging between $ 335 and $ 25,450, varying per member state, and has commenced demonstration projects throughout Europe. The Green eMotion project, for instance, is currently involved in demonstration projects in Berlin, Stuttgart, Strasbourg, Cork, Barcelona, Dublin, Madrid, Pisa, Rome and Copenhagen.

China is investing $ 14,8 billion and incentives can reach up to a maximum of $ 9,500. The Chinese government announced that five cities, including Shenzhen, Shanghai, and Beijing would be hosting demonstration projects to accelerate installation of charging equipment and to make private ownership of vehicles viable.

Japan reported to invest $ 100 million according to their older program from 2009-2010 and incentives up to $ 16,000. How much has actually been invested per country so far is unknown.

Except for the green tax, South Africa is still drafting proposals regarding electrical vehicle industry strategy and governmental incentives. The lack of governmental investment and support of locally produced EVs forced Optimal Energy to abandon the Joule project.

In summary, China is the biggest investor in e-mobility and Japan, together with Denmark and Norway, has the highest incentive rates per newly purchased vehicle.
Europe and the U.S. are most progressive in demonstration projects.

3.2 Demonstration projects: Learning by doing and doing by learning

Developments of demonstration plans are extremely important to learn about consumer charging behaviour and how EVs will operate in the real world. Funds that are provided to the chosen regions will have other beneficial aspects such as job creation, promotion economic growth, enhancement of air quality, and noise reduction, and can attract other high tech industries and leading businesses to the region. Some recent developments around the world are described in this section.

3.2.1 USA: ECOtality and Nissan

ECOtality is a company that is specialized in electric transportation and storage technologies and, recently, teamed up with Nissan. Together, they are working to bring 10 950 chargers and 4 700 Nissan Leaf EVs to five states, namely, Arizona, California, Oregon, Washington and Tennessee. ECOtality has been granted $ 99.8 million by the Department of Energy to start their electric vehicle project. Nissan recently invested $ 1 billion in a factory in Tennessee that will build lithium-ion battery packs for the Leaf and, at a later stage, the car itself. The Department of Energy has loaned Nissan $ 1.6 billion to help finance that project. Nissan plans to build as many as 150 000 Leafs a year once the factory gets rolling (Harrop & Zervos, 2011). To accommodate and stimulate the introduction of electric vehicles, Tennessee plans to install 2 190 220-volt level 2 chargers that, in normal conditions, can provide a depleted battery with a full recharge in eight hours. Nissan and ECOtality are also looking into the possibilities of installing level 3 quick chargers and are anticipating deploying 10 950 level 2 and 260 level 3 chargers in these five states. Up till the end of 2011 this was only a forecast and deployment and installation of these charging points hasn't started yet (Harrop & Zervos, 2011).

3.2.2 China

In March 2011, China Southern Power Grid (CSG) and Better Place signed a strategic cooperation framework agreement in Guangzhou, to develop an EV infrastructure in China. In December 2011, Better Place and CSG announced the opening of their Switchable Electric Car Experience Centre in in Guangzhou's Pearl River New Town. On that same day the first EV depleted battery was swapped for a new, fully charged battery and marked Guangzhou as the starting point for EV network infrastructure. The fully automated procedure only takes 5 minutes to switch depleted for charged batteries.

After extensive research, development and planning, CSG announced in July that it would follow a centralized, open, and government-led but enterprise-guided approach in providing energy for EVs. The company's strategy has battery switch at its core, combined with centralized EV charging. CSG will promote the development of national technical standards and build a smart EV network. (Business wire, 2011)

CSG has 14 EV charging stations in its network, with 2 901 charging poles in operation, and 206,000 kWh of usage over 45 000 charge cycles from January to November 2011. CSG will under government's leadership localize smart EV network infrastructure for the Chinese market and meet the needs of the five southern provinces to support development of the EV industry.

The Switchable Electric Car Experience Centre in Guangzhou is the first fully automated battery swapping station and covers over 19,000m^2. The swapping station is situated near the Guangzhou Auto Mall, which is the biggest auto mall in China. Better Place and CSG also provide battery switch demonstrations to demonstrate charging capabilities of EVs. The customer service centre makes reservations, and knowledgeable guides will accompany visitors throughout the facility and explain more about EVs (Better Place, 2011). The new swapping station can promote EV adoption and raise public awareness and acceptance of EVs, which is a very important step in promoting the smooth introduction and development of electric transportation in China.

3.2.3 The Netherlands

The Netherlands most pursued initiative regarding e-mobility is a foundation called e-laad and is an initiative of several distribution companies and the national grid company/operator. Together, they represent 75% of the total distribution grid and are trying to facilitate the large-scale roll out of electrified transportation. In order to gather important research data regarding consequences and impact on the grid and to build up experience, e-laad is installing 10 000 public charging points. Not only at strategic chosen places such as city centres and shopping malls but also makes it possible for the consumer to request a charging station in their own street (as long as it is a public terrain and not a driveway or garage) if they drive an electric vehicle. To facilitate electric transportation, they are creating a basic infrastructure of public charging points together with their partners that include several charging point providers, car dealers and lease companies. According to a recent study by Narich, Stark, Schutz, Ubbink, and Noom (2011), the up-front investment for this infrastructure has been paid for by e-laad. To make use of the facilitated charging points the costumer must become a member of e.laad.nl and pays an annual membership fee of € 100. Costumers are then able to charge as frequently as they want to throughout the year with no additional costs.

The website www.oplaadpalen.nl provides EV drivers with information about the nearest charging points, availability, level of charging, owner, payment methods and what charging equipment is used. Not only e-laad is placing charging points throughout the country but also other companies, such as Total, Nuon and The New Motion, have done so before. Therefore, it is very important that a consumer checks what method of payment is required at certain charging points. Figure 23 illustrates the publically available charging point in the Netherlands. The blue circles indicate how many charging points there are in the specific area.

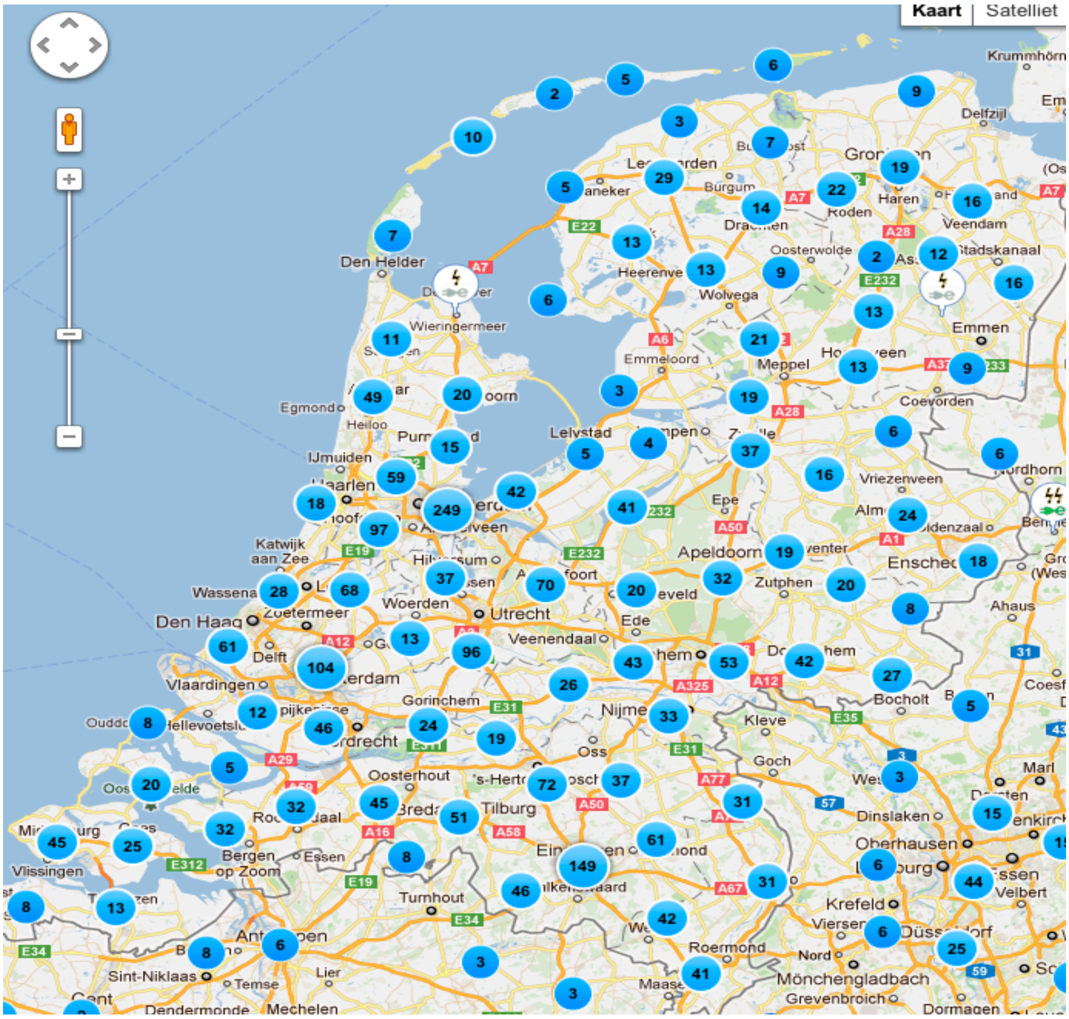


Figure 23: Representation of publically available charging points in The Netherlands (Image acquired from www.oplaadpaalen.nl)

The Accenture study conducted by Narich, Stark, Schutz, Ubbink, and Noom (2011) also reports that all activities are managed by the foundation and has a set of employees "on loan" from each of the grid companies. The foundation itself is overseen by a board that is composed of representative of each the grid companies.

Figure 24 shows the growth of installed charging point by the e-laad initiative. The blue line represents charging points that are installed at strategically chosen areas. The yellow line indicates the charging points that have been installed on request of EV drivers in front of their own doorsteps. Furthermore, Figure 24 illustrates a vast increase in installation of strategically chosen charging points after January 2011 and has reached the 1000 mark by the end of that same year.

The amount of requested charging points by consumers showed growth in March 2011 and is due to the fact that more EVs have been registered during the course of that year. E-laad charging points can be requested to be installed in the whole country, except for Amsterdam because there the municipality has chosen their own infrastructural planning regarding the placement of EV charging points.

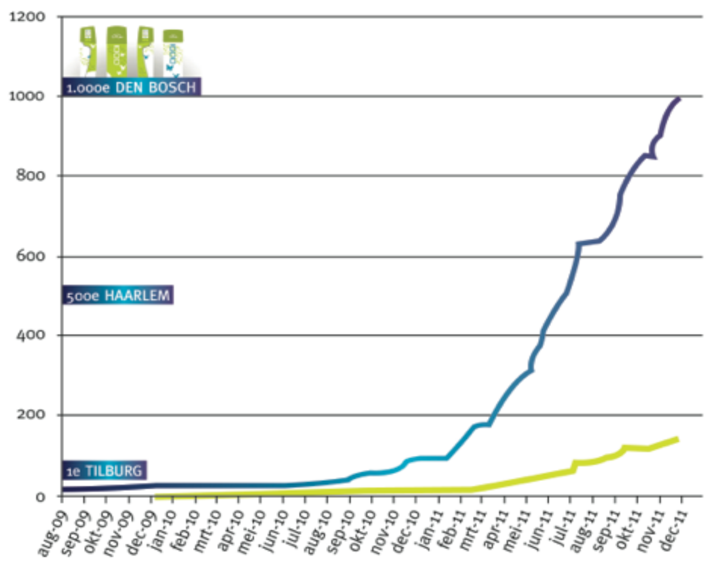


Figure 24: e-laad charging points growth from 2009-2011

According to the study of Narich, Stark, Schutz, Ubbink, and Noom (2011), there are several lessons learned which are summarized below:

- With regard to the infrastructure, the current cost of EVSE is unfeasibly high for large-scale rollout. This realization has led to a re-evaluation of much of the infrastructure design, and companies are looking into lower cost options such as different EVSE materials and manufacturers;
- The physical architecture of this infrastructure is very important, as it needs to contribute to an attractive urban setting for a wider-scale rollout; and
- The importance of standardization. Currently, every grid company has different policies regarding the meters and the connection points, resulting in a total of eight different policies and need to be standardized.

Consumer behaviour is measured by the foundation that records meter consumption every 5 minutes. This data is then made available for the different companies involved. Another interesting lesson learned, reported in the same research, is the fact that the charging infrastructure is fairly distributed over the grid, which resulted in no substantial impact or strain on the grid. Over time, more lessens will be learned in this pilot case as it is running until the end of 2012.

3.2.4 Summary

The demonstration projects per country and studied examples used different charging methods and implementation strategies. China, for instance, constructed the first commercial swapping station next to the biggest auto mall in China. Alongside to the 2,901 public charging poles that are already in operation and organizing guided tours through their swapping station, they can make potential consumers aware of EV technology, the ease of battery swapping, and promote the introduction of electric transportation in China.

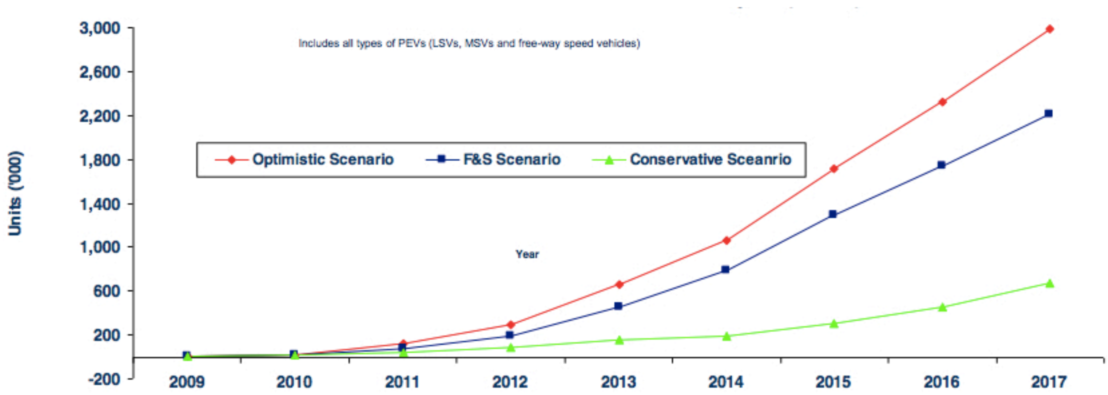
The Netherlands, in collaboration with e-laad and other companies, is developing a charging infrastructure together with electricity providers, car dealers and lease companies and, together, they are installing 10 000 public charging points in the coming years. According to oplaadpalen.nl, there are already approximately 1 800 charging poles operational.

The USA, together with ECOtality and Nissan, is still working on their demonstration plan by bringing 10 950 chargers and 4 700 Nissan Leafs to the five states previously mentioned. A vast amount has been invested in a factory to produce as many as 150 000 Leafs when the factory becomes operational. Up till the end of 2011, deployment and installation of these charging points and the anticipated Leaf production rates haven't been realized yet.

3.3 Global electric vehicle sales forecast

As described in paragraph 3.1, almost every major manufacturer has announced the introduction of their first electric vehicle in the near future or have already started production and are now commercially available. It is still highly uncertain what the consumer uptake will be. In other words, will the consumer choose electric vehicles as a new way of transportation over their, in many cases, beloved and reliable ICE vehicles? Many barriers must still be overcome in order to obtain a successful adoption rate that should result in an effective roll out of electric vehicles. Several market research groups and consultants have forecasted global EV sales and some of them are more optimistic than others. The following sales forecasts focus on the period between the years 2010 and 2021.

3.3.1 Frost & Sullivan



Scenario's	2010	2011	2012	2013	2014	2015	2016	2017	2020 (% of Total Car Sales)
Optimistic Scenario	23,100	123,800	289,500	665,000	1060,400	1,714,500	2,220,300	3,202,000	10-12
Frost &Sullivan Scenario	16,500	72,000	193,000	453,000	792,000	1,287,500	1,736,000	2,203,000	5-7
Conservative Scenario	13,500	35,600	82,500	150,300	195,100	300,500	450,000	670,000	3-4

Figure 25: 3 Global sales forecasts scenarios according to Frost and Sullivan. Illustration adapted from (Singh, 2010)

Frost & Sullivan (F&S) have forecasted three scenarios (see Figure 25), which include an optimistic, their own and a conservative scenario. According Sarwant Singh, who presented these scenarios for Frost & Sullivan, 10%-12% of the global car sales should be electrical vehicles by 2020 to correspond with the most optimistic scenario. The forecasted scenario by F&S themselves is less optimistic and predicts that there will be 427 000 less EVs on the road by 2015, as compared to the optimistic scenario. The predicted market share in 2020 will be between 5% and 7%. In their more conservative model, F&S expect that, by 2020, only 3%-4% of all vehicles sold will be electric vehicles. F&S expect significant growth in the market share of EVs after 2012 in all three scenarios.

3.3.2 IDTechEX

Dr Harrop & Dr Zervos published relatively optimistic sales numbers in their research for IDTechEX, compared to the previous F&S forecast. They foresee a much bigger EV market with sales numbers reaching the 2 275 000 mark by 2015 and 9 564 000 by 2021. This concurs with approximately 11% of the total vehicle market by 2021. Their prediction regarding the first 4 years is somewhat similar to the F&S forecast and both believe that there will be significant growth after that.

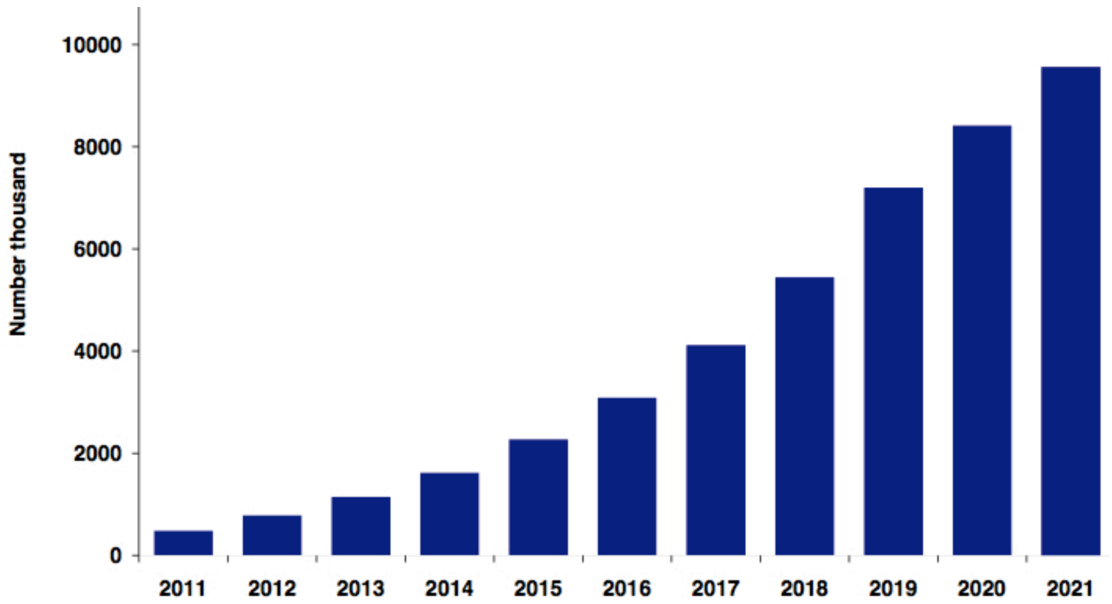


Figure 26: Global EV sales forecast according to IDTechEX. Illustration adapted from (Harrop & Zervos, 2011)

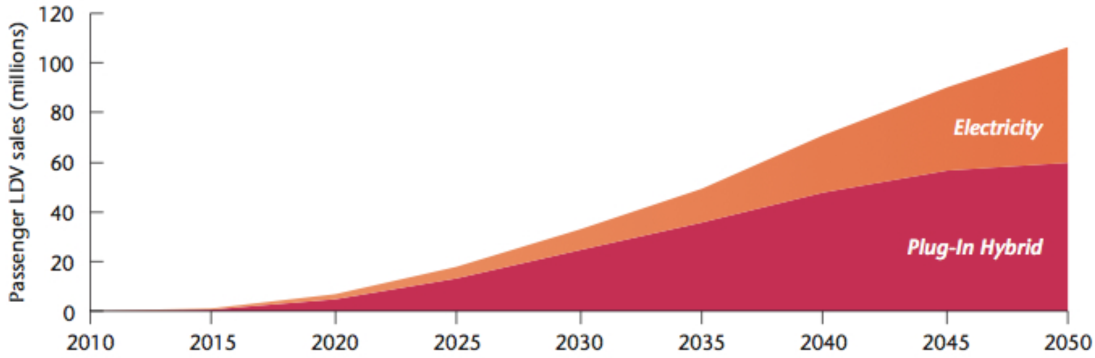
3.3.3 International Energy Agency

Figure 27 illustrates the sales forecast of the in July 2011 published technology roadmap by the International Energy Agency and is based on the Blue Map scenario. Assumptions that were made in the Blue Map scenario are described below:

- Vehicle model types and sales growth rates**:** It is assumed that a steady number of new models will be introduced over the next ten years, with eventual targeted sales for each model of 100 000 units per year. However, it is also expected that this sales rate will take time to achieve. During 2010 to 2015, it is assumed that new EV and PHEV models will be introduced at low production volumes as manufacturers gain experience and test out new designs. Early adopter consumers are expected to play a key role in sales, and sales per model are expected to be fairly low, as most consumers will wait to see how the technologies and market develop. As a result, it is assumed that from 2015 to 2020, the existing number of models and sales per model will increase fairly dramatically as companies move toward full commercialization.

- Vehicle efficiencies: EVs are assumed, on average, to have a range of 150 km (90 miles) and PHEVs' all-electric ranges are assumed to start at 40 km (25 miles), rising on average over time due to improvements in battery technologies and declining costs. Both types of vehicles are assumed to have an average in-use fuel efficiency of about 0.2 kWh/km (0.3 kWh/mile). While vehicles could potentially be made more efficient, which would increase the range for a given battery capacity or decrease battery capacity requirements, the chosen efficiency assumptions reflect a more probable outcome.
- The scenario assumes an average 150 km range EV and 40 km range PHEV, and simplifies the likely range of variation around these averages.
- For PHEVs, the percentage of kilometres driven on electricity is assumed to rise over time as recharging times diminish, electric recharging infrastructure spreads, and the number of opportunities to recharge the battery during the day increases.
- The cost of batteries for EVs is assumed to start at about USD 500 to USD 600/kWh at high volume production (on the order of 100 000 units), and drop to under USD 400/kWh by 2020. Higher per-unit battery costs are assumed for PHEVs, due to higher power requirements. PHEV batteries are assumed to start around USD 750/kWh for high-volume production, and then drop to under USD 450 by 2020. These cost reductions depend on cumulative production and learning, so if production levels remain low over the next ten years, it reduces the probability of gaining the target cost reductions, and hence reaching BLUE Map deployment targets[4].

[4] All BLUE Map assumptions are adapted from the IEA technology roadmap of July 2011 (IEA, 2011)



	2010	2015	2020	2025	2030	2035	2040	2045	2050
PHEV	0.0	0.7	4.9	13.1	24.6	35.6	47.7	56.3	59.7
EV	0.0	0.3	2.0	4.5	8.7	13.9	23.2	33.9	46.6
Total	0.0	1.1	6.9	17.7	33.3	49.5	70.9	90.2	106.4

Figure 27: Global EV sales forecast according to the International Energy Agency. Illustration adapted from (IEA, 2011)

Where the other research groups/consultants have categorized electric and plug-in hybrids as one category, the IEA have separated them in their forecast. Unfortunately, it is less accurate to compare the forecasted sales numbers with other forecasts due to the chosen time line. The IEA prediction tells more over the period from 2020 to 2050. Predicted sales levels of the total vehicles sold by 2015 ought to reach 1 100 000 and 6 900 000 by 2020. In the anticipated sales figures, the IEA assumes that more plug-in hybrids will be sold then full electric vehicles. After 2040, sales of PHEVs are expected to begin declining as EVs achieve even greater levels of market share. The ultimate target is to achieve about 50 million sales of both types of vehicles annually by 2050 (IEA, 2011).

3.3.4 Deutsche Bank

The Deutsche Bank forecasted EV sales in their in November 2009 published global market report and are based on these assumptions:

- That lithium-ion batteries power all PHEVs and EVs. For HEVs, they assumed that nickel metal hydride batteries power 85% of HEVs in 2013, 65% in 2015, 50% in 2018, and 30% in 2020. Nickel metal hydride revenue is not included in our battery market revenue forecast.

- That EVs use 25 kWh batteries, PHEVs use 12.5 kWh batteries, full hybrids use 2 kWh batteries, and mild hybrids use 1 kWh batteries.

Figure 28 represents the Deutsche Bank forecast. They estimate that the global market for EVs will rise to 5,6 million vehicles in 2015, which corresponds with 7% of the total cars sold, and 17,3 million vehicles by 2020 and concurs with a 20% market share. The Deutsche Bank also believes that more hybrid vehicles will be sold until 2015 and that full EVs will predominate after 2015 with a market share of 11% compared to the hybrid vehicle share of almost 9% by 2020.

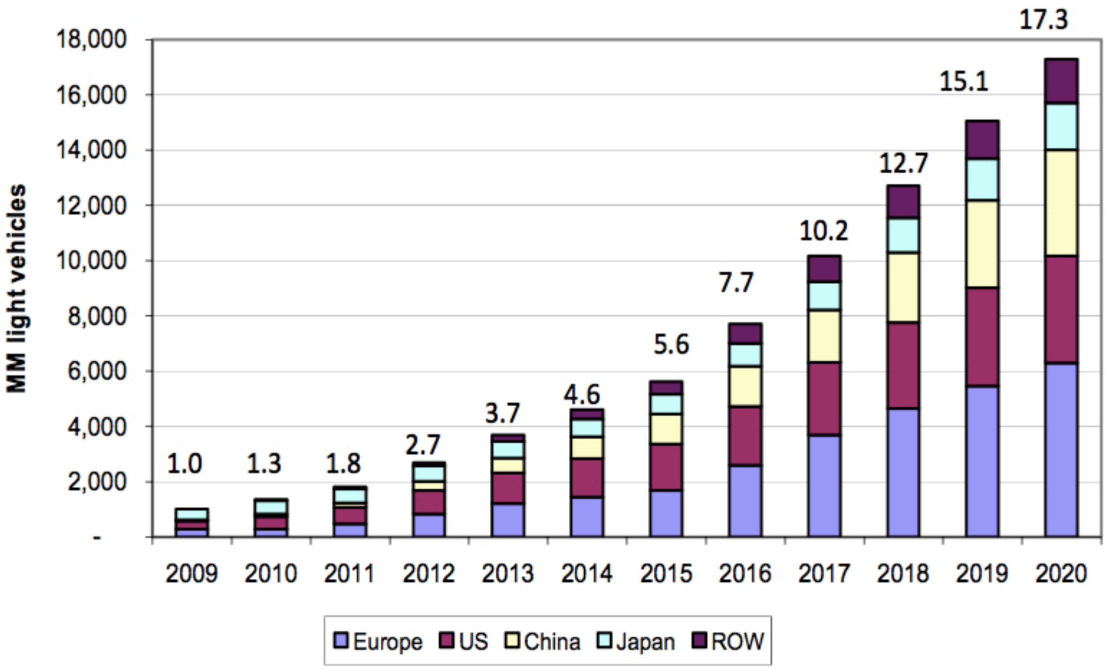


Figure 28: Global EV sales forecast according to the Deutsche Bank. Illustration adapted from (Lache, Galves, & Nolan, 2009)

In Figure 28 the total sales have been divided by region. The Deutsche Bank estimates that Europe will have a bigger sales volume then the United States around the 2015 timeframe and China is expected to catch up by 2020. The Deutsche Bank forecasts revenues as follow:

- The automotive related lithium-ion battery market will reach $18.4 billion in 2015 and $66.2 billion in 2020; and
- Revenue becomes truly meaningful in 2012 ($7.3 billion), and from that point our forecast suggests a 32% compound annual growth rate (CAGR) through 2020.

3.3.5 Comparison of forecasted global EV sales

When one compares all the different forecasts, it can be concluded that the forecasts of Frost & Sullivan, IDTechEX and the International Energy Agency have similar predictions and assumed growth rates. Due to absence of data from F&S and IEA it was not possible to illustrate their forecasts for 2015/2017 till 2020. The Deutsche Bank estimates a much bigger market share for EVs compared to the other forecasts, with prediction of total sales being 3 to 4 times higher. Figure 29 shows the same growth trend but with different forecasted sales. It is highly uncertain and difficult to conclude what the EV market penetration will be over time. Forecasts are based on assumptions and no real data has been gathered yet.

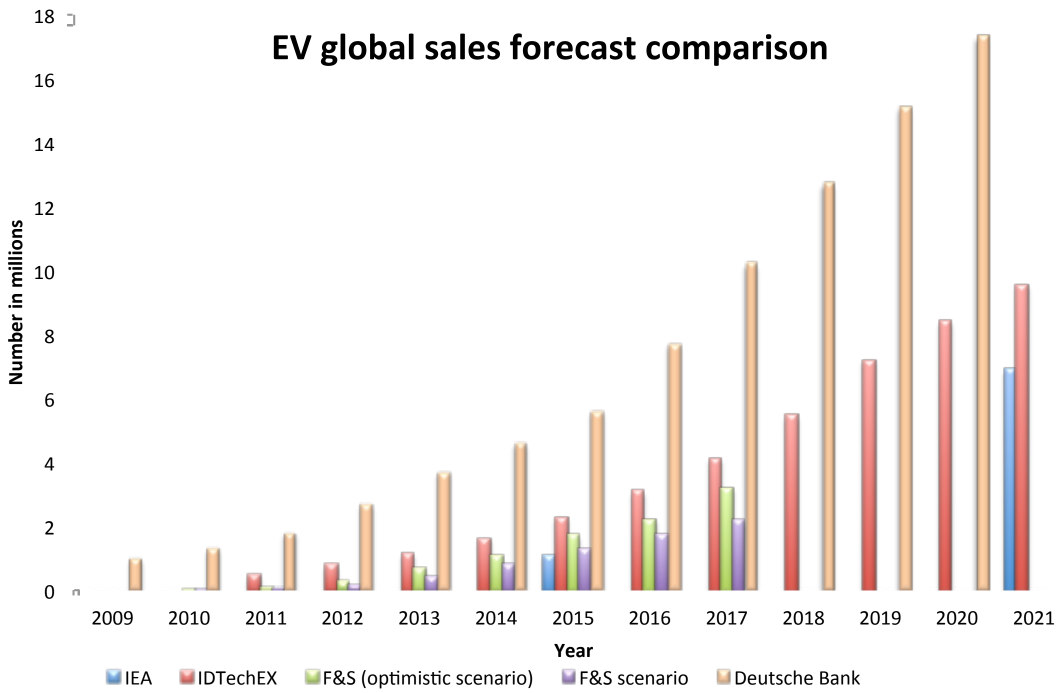


Figure 29: Comparison of global forecasted sales of EVs

IDTechEX has, next to EV sales forecasts, also created a scenario based on their same research data and conclude that there will be close to 400 000 EV charging stations sold worldwide by 2021 of which 61% will be residential chargers and 39% (see Figure 30) outdoor and destination chargers. This corresponds with 0.4 charger per electric vehicle sold. In their estimates (see Figure 31) it is clear that level 2 charging will be predominant over the lower voltage charging (level 1) and the fast but still uncertain level 3 charging. Level 2 charging is in their assumption the most probable way of electric vehicle re-charging.

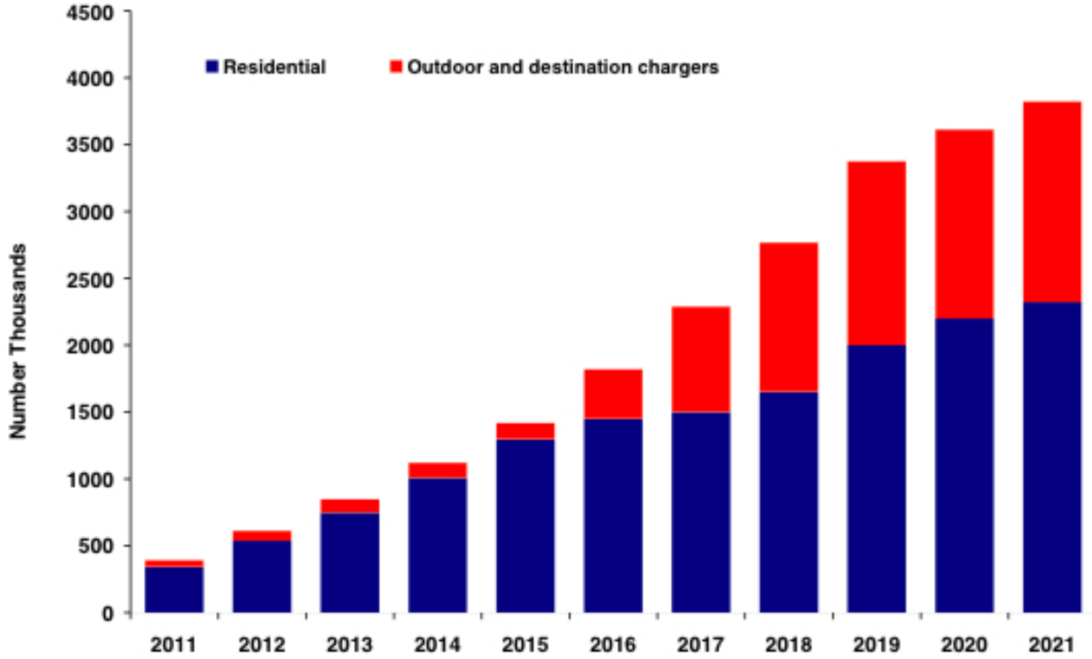


Figure 30: Number of car charging stations sold worldwide in thousands 2011-2021, residential, outdoor and destination, rounded. Graph adapted from (Harrop & Zervos, 2011)

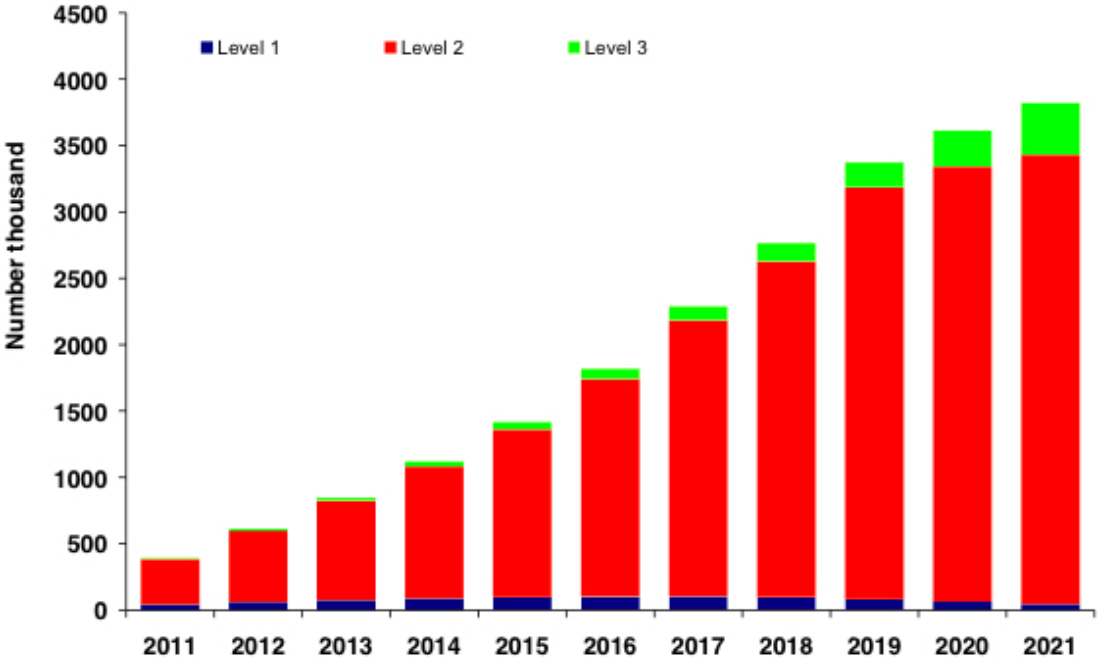


Figure 31: Numbers thousands of the three levels of charging station worldwide 2011-2021. Graph adapted from (Harrop & Zervos, 2011)

3.3.6 Conclusion

The four different global electric vehicle sales forecasts al describe growing market shares with similar tendencies. What is proven to be different is the amount of units sold over a certain period of time. Due to the difference in timelines and the fact that F&S and IDTechEX did not mentioned on what assumptions they based their predictions, the data is not 100% comparable, but is used to provide a better insight into global market trends. The reason why there is a significant difference in the estimated sales per year is due to the fact that the introduction of electric vehicles is still in an early stage. Battery life & technology, range, charging availability and performance are still uncertain. It is expected, and generally believed, that the battery price will drop because battery technology will significantly improve over time. This is expected to happen after 2015 and will stimulate the uptake rate of both PHEVs full EVs. Table 13 shows the total amount of electric cars sold in Europe and the United States.

Table 13: Number of EVs sold per country and year.

	Electric Car Volumes			
Country	**2009**	**2010**		**2011 (Jan-Jun)**
		First half	**Full year**	**First half**
Austria	39	46	96	347
Belgium	0	11	34	85
Czech Republic	-	0	4	43
Denmark	20	6	15	283
France	10	22	133	953
Germany	158	62	185	1020
Ireland	1	15	17	36
Italy	50	9	40	103
The Netherlands	0	52	87	269
Norway	331	140	353	850
Portugal	0	0	18	93
Romania	-	0	0	2
Spain	0	21	76	122
Sweden	15	1	5	111
Switzerland	-	88	167	239
United Kingdom	179	29	90	599
USA	-	-	-	6707
Additional markets	-	3	16	76
Total	**803**	**505**	**1336**	**11938**

Note: Additional markets include Croatia, Estonia, Finland, Hungary, Luxembourg, Serbia, Slovakia and Slovenia
Source: Jato press release of 26 September 2011; Incentives fail to stimulate European electric vehicles sales. (Jato, 2011)
USA: www.hybridcars.com

Germany is considered the market leader in Europe despite lower subsidiaries and incentives compared to other countries. Although Denmark has the highest potential tax advantages and incentives, they only sold 283 EVs during the first half of 2011. Noteworthy is the amount of EVs sold in Great Britain and Spain. While they have similar subsidiaries and incentives programs, the U.K. sold over 5 times more electric vehicles in comparison with Spain. The sales numbers in Table 13 show that incentives in Europe failed to speed up introduction of e-mobility and it's likely that other factors, such as available charging infrastructure (pointed out in paragraph 3.2.3.), battery and petrol/electricity cost, play a more significant roll.

In 2010, only 1336 EVs were sold in Europe, while the Deutsche Bank forecasted in July 2009 that there would be 280 000 EVs sold in Europe by that time. In Europe and the US, a big increase in sales units of 88,80% was noticed during the first half of 2011 and 11 938 units were sold during these first 6 months. If we assume that during the second half of 2011 the same amount of EVs has been sold, then a total of 23 876 vehicles will be sold during the course of the year. To put the forecasted total sales in perspective and to reach the by the Deutsche Bank predicted 17,300,000 electric vehicles on the road by 2020, sales in Europe and the US must double each year in order to get 12 224 512 EVs on the road, and the rest of the world has to account for the missing 5 075 488 EVs. At this stage, it is highly unlikely that EV sales numbers will double per annum over the next 8-10 years. If sales were to increase by 80% every year, sales of 4 736 026 EVs can be realized and assuming that the rest of the world will produce another 2 000 000, bringing the total global EV production to approximately 6,7 million, the predictions of IDTechEX, F&S and the International Energy Agency can be considered as somehow accurate.

4 CHAPTER FOUR – RESULTS AND DISCUSSION

This chapter describes the challenges and possible barriers for electrified transportation, the different business models and a detailed cost analysis in which the key variables affecting the viability of e-mobility are identified.

4.1 Challenges facing the electrification market

4.1.1 Consumer acceptance

Consumer acceptance is a key figure in the success or failure of electric transportation. According to Jarigese, et al. (2010), the four most important aspects for the successful implementation of EV technologies are petrol/electricity prices, adequate recharge infrastructure, battery technology and total cost of ownership. This means that EVs must be cost competitive with ICE vehicles. Another important barrier is safety. In this paragraph the key barriers (see Figure 32) for adoption of electric transportation are explained and discussed.

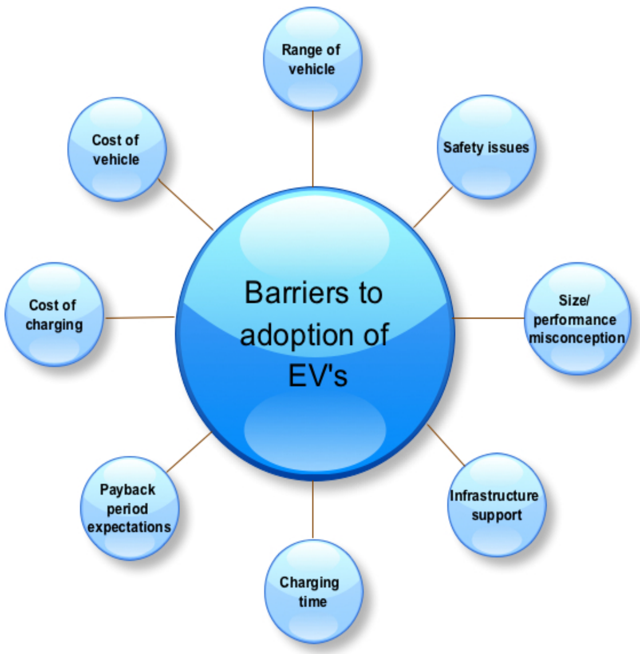


Figure 32: Schematic representation of EV adoption barriers. Based on a model of (Jarigese, et al., 2010).

4.1.2 Vehicle range

The kilometres that can be travelled with a fully charged battery are still a major obstacle for consumers. Current manufactured batteries have range limitations and, on average, a fully electrical powered vehicle can drive up to 130–180 km. There is high performance or premium electric vehicles on the market, such as the Tesla roadster and the Tesla model S that can drive up to 390 and 480 kilometres per charge respectively. The new Tesla model S, with an 85 kWh battery, provides a range up to 480 kilometres and is, i.e., priced at USD 69,900 after federal tax credit for the U.S. market (Tesla Motors, 2011). For the majority of the potential electric drivers, these premium electric cars are too expensive and not everybody can afford it. The more mid-range priced vehicles, like the Nissan Leaf, are more likely to be the most popular vehicles to be adopted for electric transportation. The Leaf is just like the Tesla vehicles, available in many countries and is, for example, available from USD 27,000 after federal tax credit (depending in which geographical state the vehicle is purchased, i.e., California or Texas) in the U.S. and has a range of 175 kilometres per charge (Nissan, 2011). All range numbers are dependent on drive style, servicing history and operating temperature of the vehicles. A lack of recharging infrastructure creates concerns for early adapters. Not being able to fuel up whenever necessary, as with an ICE vehicle, can create range anxiety and going for trips over a certain distance requires planning. Hybrid and range extended vehicles have a bigger range due to the fact that they are powered by an ICE and an electrical motor but are still higher priced then conventional vehicles (Tsang, Pedersen, Wooding, & Potoglou, 2012).

4.1.3 Cost of ownership

The upfront cost is another barrier for potential EV buyers and incentives are likely to have no effect to reach the break-even point in the near term. Future battery prices are uncertain but expected to drop over time. Auto garages and other service providers are not yet ready to service EVs and exact prices for these services and spare parts are not yet known. An example of the total cost of ownership of a standard electric vehicle is described in detail in paragraph 4.3.

4.1.4 Infrastructural support and required charging time

A much-discussed topic is the time required to recharge a fully discharged battery. Different levels of charging are available and it has been proven that level 2 charging will be the most likely, and generally accepted, charging method. Level 2 chargers can be installed at residential houses and people who use their electric car for daily trips under about 120 km don't have to recharge at publicly available chargers but can charge at home overnight. The downside to this, however, is that EV owners need to have covered or indoor parking facilities. When home charging is not available, EV drivers have to rely on public chargers. Until now, not many charging spots are operational but many countries are working on this as previously described in chapter 3. The author believes that public charging availability will have a tremendous effect on EV adoption due to its psychological effect. When public charging stations are installed, early adopters who charged previously at home will be able to drive longer distances, and thus will be demonstrating and promoting EVs over larger regions. This will result in a higher rate of EV adoption since people see that the vehicle range has been extended and will most probably have a freer and less limited feeling to travel.

4.1.5 Payback period

The payback period of a newly purchased vehicle has not yet been proven. Large scale production, improving battery technology, 2nd hand batteries and components will all have an impact on this. Since electric transportation and introduction of electric vehicles is still in an infant stage, it is yet undefined as to what the payback period will be, but rapid battery cost degradation and increasing differences in prices of energy sources to propel the vehicles will contribute significantly to a shorter payback period. Forecasted break-even points and key variables affecting the payback period are modelled and discussed in paragraph 4.3.6.

4.1.6 Size and performance

Battery size and performance is still one of the limitations at present. A standard lithium battery pack that can cost up to half of the total vehicle price (Tsang, Pedersen, Wooding, & Potoglou, 2012) typically stores in the order of 35 kWh (Gaines & Cuenca, 2000). According to Electeropedia (2009) an EV battery weighs about 7kg per kWh. This means that batteries with capacities between 30 kWh and 50 kWh, as envisaged in the average car, at present would bring the battery pack total weight to an approximate 210–350 kg. Amirault, et al. (2009) have modelled battery size and weight in their research and conclude that a battery pack for an EV sedan will weigh between 303–352 kg, depending on what type of lithium battery is used. The battery is thus a large part of the total vehicle weight and makes the vehicle, in general, heavier than small ICE vehicles. Acceleration and top speeds of standard electric vehicles are, for now, lower than standard ICE vehicles. EVs can't compete just yet with ICE vehicles when it comes to performance and will have a different way of utilization in the early stage of electric transportation. One must think of urban use, 2 wheelers, public transport and government fleets. Only when technology improves, could EVs potentially replace ICE vehicles.

4.1.7 Safety issues

Another important barrier to adopt electrified transportation is safety issues. Fully battery powered EVs produce almost zero noise. This is a benefit for city centres but is also a safety concern for all other traffic participants who are used to surrounding noise, especially for the hearing impaired. Road assistance (such as AA) might not be available yet due to the lack of relevant knowledge about repairs of EVs and emergency officials, such as fire fighters, need to be trained in what to do in case of accidents and other emergencies. With the coming of electric transportation new questions arise, such as what fire extinguishing method should be applied. Therefore, education and training of personnel is very important to make e-mobility a safe way of transportation. The US, for example, has started a project that is funded by the Department of Energy, called the electric vehicle safety training, and it has become the duty of the national fire protection association to educate everybody who is involved with EVs and safety (NFPA, 2012).

4.2 Business models

To facilitate large-scale electric vehicle adoption, new business models to overcome high battery costs have to be developed. Innovative business models are expected to offer certain packages that will satisfy consumer needs. Various possible business models are based on the following principles:

- Battery leasing;
- Battery swapping;
- Vehicle leasing; and
- Car clubs.

According to Essen, Braat, Kampman and Gopalakrishnan (2011), there are models of ownership emerging with a number of variations of 'in-between' models. The models illustrated in Figure 33 focus on the different battery ownership possibilities. Model 1 is similar to the conventional model of car ownership and focuses on vehicle purchase including the battery. Charging of the vehicle will happen at home or at public charging points if a recharging infrastructure is in place.

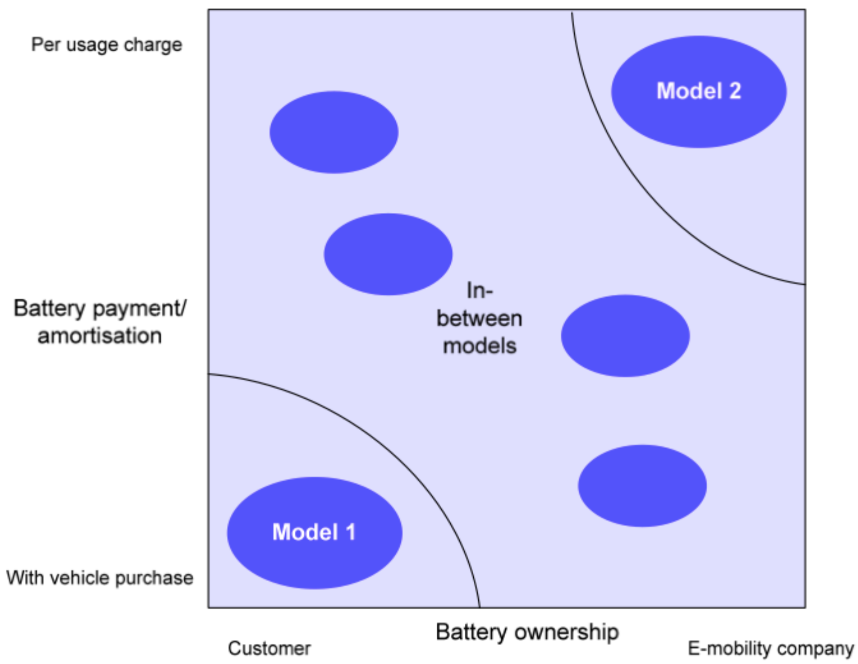


Figure 33: Potential ownership models. Adapted from (Essen, Braat, Kampman, & Gopalakrishnan, 2011)

Model 2 is based on an organization that sells a mobility service instead of an actual product. The company owns the battery and develops a battery charging and exchange infrastructure and customers are then charged for the electricity used to charge, as well as the battery amortization. Model 2 offers customers a similar sales price to that of ICE vehicles but they don't have the risk associated with battery degradation and lifespan because the battery is supplied and maintained separately from the vehicle.

4.2.1 Battery leasing

Battery leasing is a variation of model 2. In this particular business model, the vehicle is acquired without the battery and the consumer signs a lease contract for a certain period of time. Payment is based on a monthly 'fee' that has been established before the purchase of the vehicle. It is most likely that one leases the battery from the car manufacturer itself instead of through a third party company. Renault sells its zero emission (Z.E.) vehicles according to this business model. See Table 14 for all Renault Z.E vehicle and battery leasing prices for the United Kingdom.

Table 14: Vehicle and battery leasing costs for the Renault Z.E. models in the U.K.

Model	Vehicle price (excluding Tax and incentives.)	Battery leasing costs per month
Kangoo Van Z.E.	£16,990	£59 excluding VAT per month for Kangoo Van Z.E. and Kangoo Van Maxi Z.E. up to 9,000 miles per year (4-year renewable agreement)
Kangoo Van Maxi Z.E. 2-seater	£17,990	
Kangoo Van Maxi Z.E. 5-seater	£18,690	
Fluence Z.E. Prime Time	£17,850 (OTR after government incentive)	£69 including VAT per month for Fluence Z.E. up to 9,000 miles per year (3-year renewable agreement).
Twizy	From £6,690	£40 including VAT per month for Twizy up to 4,500 miles per year (3-year renewable agreement)

OTR: On The Road.
£1 = R 12,60 (as of 22-04-2012)
Data adapted form: (Renault, 2011)

The Renault Fluence Z.E., which is a luxurious sedan, will cost £ 17,850 after government incentives and a full year battery lease contract will cost £ 828, bringing the vehicle, including the battery, to a total cost of £ 18,678 (about R 235,322) for the first year. By purchasing the vehicle without the battery the manufacturer retains liability of the battery and commits to replacing the battery if it is not functioning as to its 'as new status'. By leasing a battery, the owner significantly reduces his own financial risk since the battery is proven to be the most expensive part (see section 4.3.1), and its lifespan has only been estimated but yet remains unproven.

4.2.2 Battery swapping model based on the business model of better place

Another business model that is somewhat based on model 2, is the principle of battery swapping. Better Place is one of the companies who are working on the battery swap business model. The required swapping stations have been discussed in paragraph 2.3.3. Renault developed, in collaboration with Better Place, swapping stations called the quick drop to provide their customers with a greater range. Figure 34 resembles an illustration of the proposed battery swapping station. The company plans to own the charging points and battery swap stations as well as the car batteries. The image is acquired from (Hennequet, 2011). Note that in the legend vehicle departure is indicated with number 4 but this should have been 8).

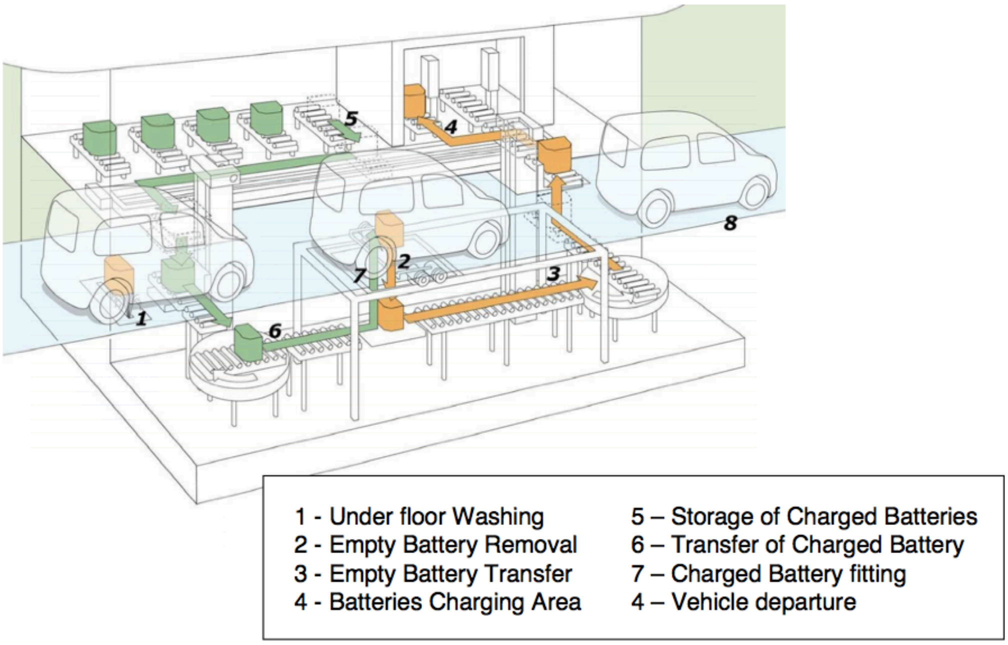


Figure 34: The quick drop station developed by Renault in collaboration with better place.

By swapping batteries, vehicle ranges will be extended significantly. It has been shown that it takes less than 60 seconds to swap a completely depleted battery for a full one (see paragraph 2.3.3). According to this business model, drivers should be able to swap their batteries during their travels at dedicated swapping stations around the country. It is based on a model used in the mobile phone industry. Customers purchase the vehicle coupled with a subscription service that covers battery replacement, charging and all other running costs (Essen, Braat, Kampman, & Gopalakrishnan, 2011). A major setback to this business model is the present lack of charging facilities and battery sizing standards. For instance, the Nissan Leaf has a completely different shaped battery than the Renault models. Therefore, it is impossible to swap batteries of different vehicle manufacturers and even models unless a vast number of different batteries are stocked. This would complicate swapping procedures and it is doubtful whether this model will be feasible in the near future. In order for battery swapping to be successful, battery charging, inventory and sizing standards need to be developed.

4.2.3 Vehicle leasing

Vehicle leasing is the extension of battery leasing. The model is based upon a leasing contract with the supplier, and the vehicle and battery are the property of the supplier. This model also significantly reduces financial risk and upfront costs, but at the same time excludes the vehicle leaser from the emerging second hand market. Mitsubishi is currently pursuing vehicle leasing as the initial business model for the i-MiEV electric small car (Hazeldine, Kollamthodi, Branningan, Morris, & Deller, 2009).

4.2.4 Car sharing clubs

Car sharing clubs have already been established for ICE vehicles in most parts of Europe and the U.S. The car sharing business model provides opportunities for future ownership models for electric vehicles. Members of these car sharing clubs are charged on the 'pay as u go' principle and only pay for the kilometres that have been driven. Again, users pay a subscription and usage fee, thus eliminating any additional and upfront cost. The location of the nearest available vehicles can been seen online and can subsequently be booked, reserved and paid for. By using a special key card that is provided with the sharing subscription, the driver goes to the pickup station (i.e., shopping mall or public transport stations) and can unlock the car during the booked and paid for time period. Figure 35 shows car sharing clubs operating in Europe.

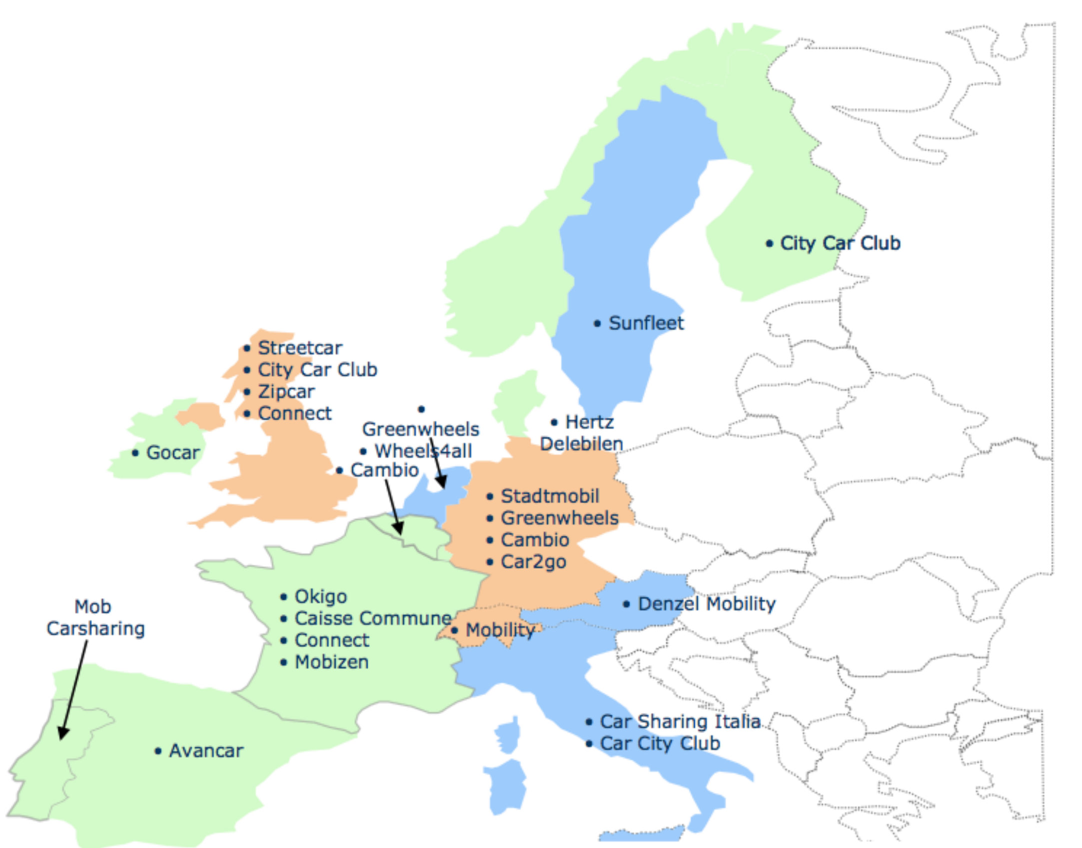


Figure 35: Car sharing clubs in operation in Europe (Singh, 2010)

Orange zones represent areas with more than 80 000 members, blue areas between 15 000 and 80 000 members, and green zones represent areas with fewer than 15 000 members. Germany and the U.K. both have 4 different car sharing clubs and over 80 000 members and are thus the biggest car sharing countries in Europe. Another benefit of the car sharing business model is that it makes it possible for consumers to test drive EVs in real world conditions without the need to make a major financial commitment (Hazeldine, Kollamthodi, Branningan, Morris, & Deller, 2009) and this could help introducing EVs in the short term.

4.3 Costs of ownership

4.3.1 Battery cost model of the Deutsche Bank

The following cost analysis is based on the battery cost forecast/scenario of the Deutsche Bank and Eskom's electricity prices assuming level 2 charging.

The biggest barrier for the electrification of transportation is believed to be the energy storage in battery packs and the cost of it. Batteries take the largest cost part of the total vehicle price for its account. Although the price of EV batteries is decreasing, industry-published reports quote battery prices in the range of $ 500-$ 700/kWh at high volume production (or $ 12,500–$ 17,500 for a 25 kWh battery pack that would propel a standard sedan EV about 160 kilometres per charge). EV batteries will inevitably degrade, but specific treatment of EV batteries can affect how slow or fast they degrade. One key consideration is temperature. Extreme charge/discharge conditions result in batteries heating up and increasing the rate of degradation. Depending on battery chemistry, frequent use of quick charge could reduce the lifespan of a battery substantially (Wolkin, 2009). The cost of lithium-ion batteries has decreased by over 75% in the past decade and the batteries are expected to perform for over 8 years and 2 000 recharges. If each charge gets 160 kilometres, the battery is projected to last 320 000 kilometres (Better Place PLC, 2009).

Table 15: Cost breakdown of lithium-ion battery (assuming scale of 100 000 per year)

Cost work-up for 180 Watt-Hour Nickel / Manganese / Cobalt cell (NMC Cells)
Assume production for approx 100k 25kWh EV packs per year

	Units	Amount	$/Unit	$/Cell	$ / EV Battery (25 kWh)	$ / kWh
Cathode active materials	kg	0.34	33.0	11.1	1,663	66.5
Anode active materials	kg	0.16	20.0	3.2	477	19.1
Electrolyte	kg	0.15	20.0	3.0	447	17.9
Separator	m2	2.03	2.0	4.1	608	24.3
Copper foil	kg	0.07	18.0	1.2	184	7.3
Can & headers & terminals	cell	1	7.0	7.0	1,050	42.0
Other materials	cell	1	2.5	2.5	375	15.0
Total Material Cost				**32.0**	**4,803**	**192.1**
Labor / Factory Overhead (est. 35%)				17.2	2,586	103.5
Total Cell Cost				**49.3**	**7,390**	**295.6**
Mechanical components (heating, cooling, fasteners)					2,053	82.1
Electrical connectors					299	11.9
Electronics (battery mgmt. system)					1,381	55.2
Labor					268	10.7
Pack Manufacturing / Electronics / Vehicle Integration					**4,000**	**160.0**
Total Pack Cost (25 kWh pack)					**11,390**	**455.6**
Warranty (2% of pack cost for 3yr warranty) - DB est					228	9.1
Gross Profit (30%)					4,979	199.2
Total Pack Price (25 kWh pack)					**16,596**	**663.9**

Source: Advanced Automotive Batteries, USABC, DB Estimates.

Data adapted from (Lache, Galves, & Nolan, 2009).

Table 15 describes a detailed breakdown of the costs of a lithium-ion 25 kWh battery pack and is based on the assumption that 100 000 battery packs are produced. They conclude that, for a 25 kWh lithium-ion battery, one must expect to pay USD 16,596 which comes down to USD 663.9 per kWh. The Deutsche Bank forecasts a decrease in battery prices of 25% by 2015 and 50% by 2020 based on their research outcomes and believe that following factors can drive the costs reduction:

- Internal economies of scale;
- Material supplier economies of scale;
- Design changes that remove components, and increase energy density; and
- Chemistry changes.

The forecasted battery cost reduction in the scenario of the Deutsche Bank is supported by a recent analysis from PRTM (Pittiglio, Rabin, Todd & McGrath) management consulting. Their results are illustrated in Figure 36.

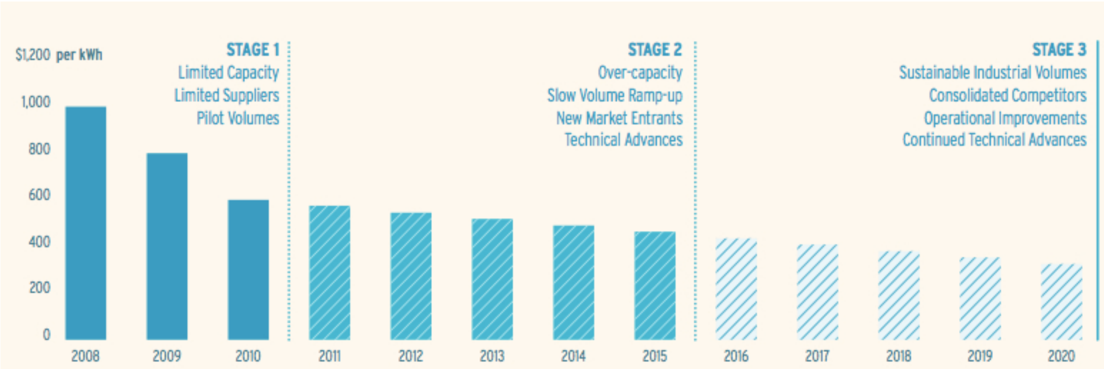


Figure 36: Results of battery cost reduction analysis conducted by PRTM consulting. (Electrification coalition, 2010)

Although the Deutsche Bank seems to be slightly more optimistic about battery cost reduction, it is generally believed that in the next 10 years battery cost will decrease significantly. The importance of battery cost degradation on the viability of e-mobility is discussed in more detail in paragraph 4.3.6.

4.3.2 Other vehicle components

Next to the battery pack there are other vehicle components that are required for propulsion of an electric vehicle. Table 16 describes the difference between ICE and electric vehicles components.

Table 16: Cost EV-specific components excluding battery, compared with cost of ICE components unnecessary to an EV

ICE-only components	USD per unit	EV-only components	USD per unit
Engine/exhaust, fuel system	2,000	Motor transmission	1,400
Transmission	800	Power electronics	1,200
Other components	200	Charger / junction box	700
		Wiring harness	600
		Heating / cooling	400
		Regenerative braking	100
Total	**3,000**		**5,000**
Data adapted from (Lache, Galves, & Nolan, 2009)			

The component costs for an EV are thus more expensive than those of ICE vehicles. In the past decades, millions of ICE's have been manufactured and this mass manufacturing led to price reductions over time. The same is expected for EVs and their components when production scales will be scaled up. Also, the simpler design of EV components should rapidly reduce production cost.

4.3.3 Maintenance costs

Maintenance costs are expected to be lower for EVs compared to ICE vehicles. For instance, oil changes, spark plugs, oil filters, air filters, cooling system liquids, and drive belts are not required for an EV to function. Expensive transmission service/repair is also not required because of the use of a single speed gearbox. Sealed motors with not many moving parts also result in lower maintenance costs.

Nissan's International product planning and zero emissions vice president, Pierre Loing, states in an interview with Engineering News that they expect maintenance to be around 15% cheaper than conventional servicing (Venter, 2012).

O'dell (2011) reported in an article in the Auto Observer that Ford did a comparison of maintenance costs between its Ford Focus Electric and its fuel Focus over a 10-year, and 240,000 kilometres life cycle. It considered savings in oil changes, air filter replacements, cooling system flushes and transmission check-ups, concluding that the Focus EV owner stands to save about $ 1,200 over a 10 year period.

According to Touchstone Energy (2011), the U.S. ostal Service tested six pure electric vehicles in its fleet and found that their average maintenance costs were $ 0.122 per mile, which is about 54% of the average maintenance costs for the fleet's conventional vehicles. The U.S Department of Energy also calculated the costs involved for maintenance and came to the conclusion that tires and other maintenance cost are $ 0,054 per mile (U.S. DOE, 2011).

The results of these tests and studies support the expectation that maintenance cost of an EV will be lower than that of ICE vehicles.

4.3.4 Home charging equipment

Due to the absence of commercially ready EV home chargers there are no fixed prices or price indications available. According to Siemens South Africa Digital Media Specialist, Dale Ladner, there are no prices being disclosed because the product itself is not available yet. "We are still in a position locally where e-Mobility is a "future" technology; the reason is that there is no infrastructure to support it. The push towards e-Mobility must come from the government and then Siemens can implement the relevant technologies to create the infrastructure. Only at this point will we start to have indications of costs for the individual components. At this point I couldn't even make an educated guess" (Ladner, 2012). The GE WattStation, a commercially ready home charger that is available in Europe and the US, delivers a 24 kW Level 2 charge in 4-8 hours. On the $ 3000-$ 7000 public versions, payment can be done by credit card. Home versions are priced around $ 1500, with federal tax credit covering half of that according to Harrop and Zervos (2011). GE South Africa could not disclose any additional information regarding possible pricing of charging equipment for the South African market. However, assuming that a level 2 home charger will be priced in SA similar to the U.S. market price, a charger would cost around R 12,500.

4.3.5 CO_2 emission rates and fuel & electricity costs

Table 17 shows a comparison between efficiency and emission of certain vehicles and its operational costs in Cape Town. When one compares the kgs of CO_2 emitted per 100 km, the Nissan Leaf shows a significantly higher emission rate then the ICE vehicle and the hybrid vehicle. Although the Nissan Leaf emits zero CO_2 while it's functioning (so called tank-to-wheel efficiency), it still emits almost 1 kg of CO_2 per kWh that is generated. This is due to the fact that Eskom produces 0.99 kg CO_2 to generate 1 kWh (Eskom, 2011). So even though the vehicle doesn't emit any CO_2 while it's being driven, CO_2 has already been produced and emitted for the generation of the required power to propel the vehicle and thus has a negative effect to the well-to-wheel efficiency of the Nissan Leaf.

Table 17: Comparison between efficiency and operational costs in Cape Town

Brand and model	Efficiency	Conversion factor	kg's CO_2 per 100 km	Rand per unit Including VAT	Cost per 100km
VW Polo sedan 1.4 Trendline	5.9 litres per 100 km	2.3117 kg's of CO_2 per litre of petrol	14.10	R 11.59 per litre (current unleaded petrol price Cape Town)	R 68.38
Nissan Leaf	17.3 kWh per 100 km	0.99 kg's of CO_2 per kWh *	17.13	R 1, 22 (current cost per kWh of electricity in Cape Town)	R 21, 11**
Toyota Prius Advanced	4.2 litres*** per 100 km	2.3117 kg's of CO_2 per litre of petrol	9.71	R 11.59 per litre (current unleaded petrol price Cape Town)	R 48.68

Source: (Urban Earth, 2012)
Additional information - www.vw.co.za; www.nissan.co.za; www.toyota.co.za
*Eskom integrated report 2011 (Eskom, 2011)
** Depending on commercial or domestic and monthly usage. Usage amount is divided in tariff blocks. This figure is based on domestic and highest tariff block and is the most expensive option.
*** Combined petrol-electric fuel economy rating (www.epa.gov)

The Society of Motor Manufacturers and Traders (2011), compared car emissions of typical pure electric vehicles to emissions from small to medium sized ICE cars. Note that electricity production decarbonizes through an increase in low carbon generation, and thus the overall emission figure for running an EV will drop further in due course.

Pure-EV 'tank to wheel' average = 0g CO_2/km
Pure-EV 'well to tank' average = 77g CO_2/km
Pure-EV 'well to wheel' average= 77g CO_2/km

ICE 'tank to wheel' average = 132.3 g CO_2/km
ICE 'well to tank' average = 14.7g - 29g CO_2/km
ICE 'well to wheel' average= 147g - 161.3g CO_2/km

To calculate the annual fuel/electricity cost for the three vehicle types discussed above, it is assumed that the average person in South Africa travels 40 km/day, as mentioned earlier, for 7 days a week (weekends are included because people travel when on weekend leave (Department of Transport, 2011)) for a duration of 52 weeks, the annual kilometres driven will be 364 days times 40 km or 14 560 km per annum. This is less than the estimated 20 000 km per annum, which is an estimation that is frequently made when a new vehicle is purchased (Automobile Association, 2012). A quick calculation shows the annual fuel/electricity costs per engine/motor type per year. Presently, internal combustion engine vehicles are becoming more fuel efficient. For example, the Volkswagen Polo sedan 1.4 trendline uses 5.9 litres of fuel per 100 km travelled. That is 16,95 km/litre (NAAMSA, 2012).

$$\frac{14560\,\frac{km}{annum}}{16{,}95\,\frac{km}{L}} = 859\,\frac{litres}{annum}$$

Equation 1: Annual fuel cost for the Volkswagen Polo sedan 1.4 trendline ICE vehicle

$$\frac{14560\,\frac{km}{annum}}{23{,}81\,\frac{km}{L}} = 611{,}5\,\frac{litres}{annum}$$

Equation 2: Annual combined fuel-electricity cost for the Toyota Prius Hybrid vehicle

$$\frac{14560\,\frac{km}{annum}}{5{,}78\,\frac{km}{kWh}} = 2519\,\frac{kWh}{annum}$$

Equation 3: Annual energy cost for the Nissan Leaf electric vehicle

With the current unleaded petrol price, including VAT, being R 11,59 per litre and the electricity price R 1,22 per kWh, including VAT (based on block 2; >600kWh usages per month), in Cape Town, the annual fuel/energy cost for the different vehicles will thus be:

Volkswagen polo sedan 1.4 trendline ICE:	R 9 956
Toyota Prius Hybrid vehicle:	R 7 087
Nissan Leaf full electric vehicle:	R 3 073

The Volkswagen ICE vehicle is consequently 3 times more expensive on fuel per year compared to the energy that is needed for the Nissan Leaf full electric car. The Toyota Prius hybrid car is cheaper on fuel/energy cost in comparison with the ICE vehicle but is almost 2,5 times more expensive then the full electric vehicle.

4.3.5.1 Forecasted petrol/electricity prices

Figure 37 shows the unleaded 95-petrol price fluctuation from May 2001 until May 2012 in the Gauteng area. Price calculations were carried out by The Central Energy Fund (CEF) on behalf of the Department of Minerals and Energy (Sasol, 2012).

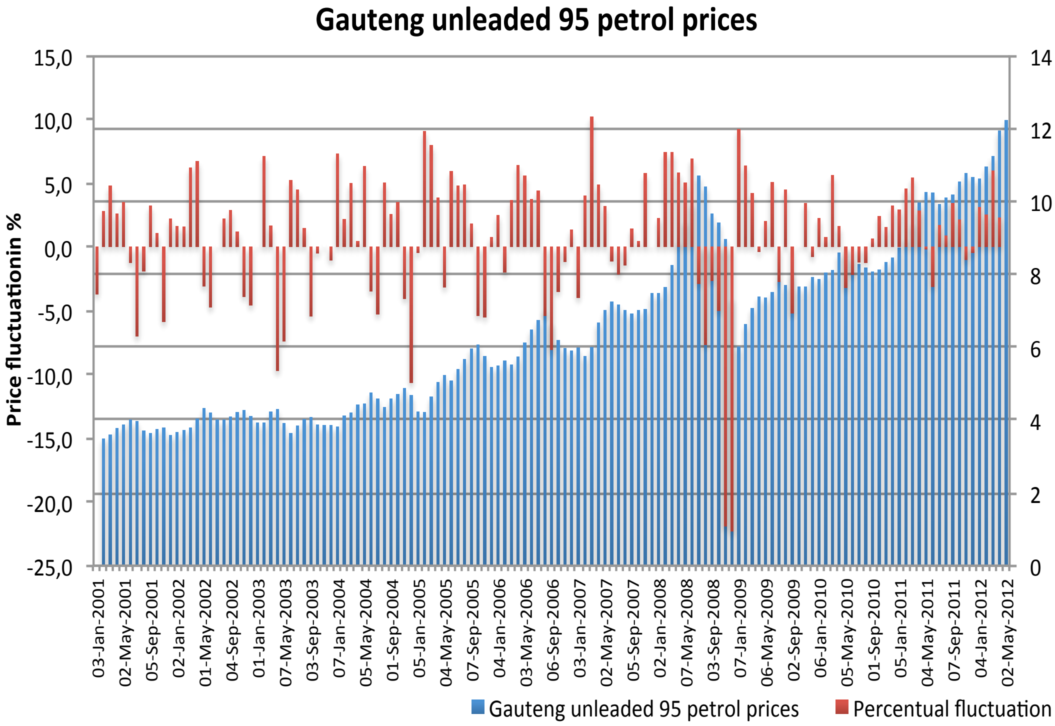


Figure 37: Overview of the Gauteng petrol prices between 2001 and 2012.

The figure shows a price increase of roughly 300% over the whole period and approximately a 9% annual increase on average. Figure 38 is an enhanced representation of Figure 37.

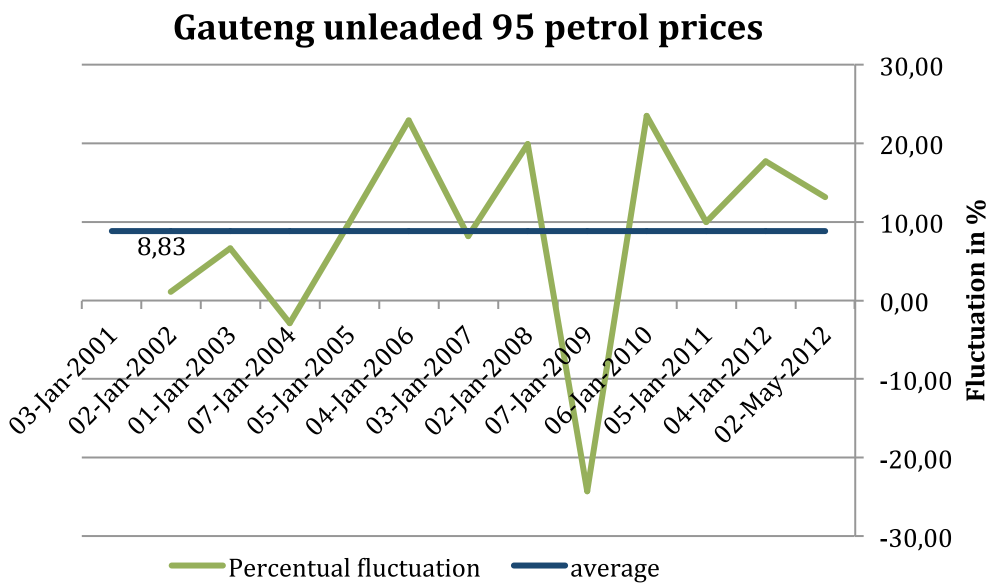


Figure 38: Average price fluctuation of the Gauteng area petrol prices.

During these 11 years, the Gauteng area saw an average petrol price increase of 8,83%. Three major price increases were observed around January 2006, January 2008 and

January 2010. The largest price reduction was in the beginning of 2009. Annual petrol price increases in the TCO calculation are based on a global market research report from the Deutsche Bank and data acquired from Sasol (2012). According to the Deutsche Bank, it is believed that the petrol price will see an annual increase of 10% worldwide (Sankey, Micheloto, & Clark, 2009). It has not been specified until what year.

Eskom's electricity tariff history from 1993 until April 2012 is represented in figure 39.

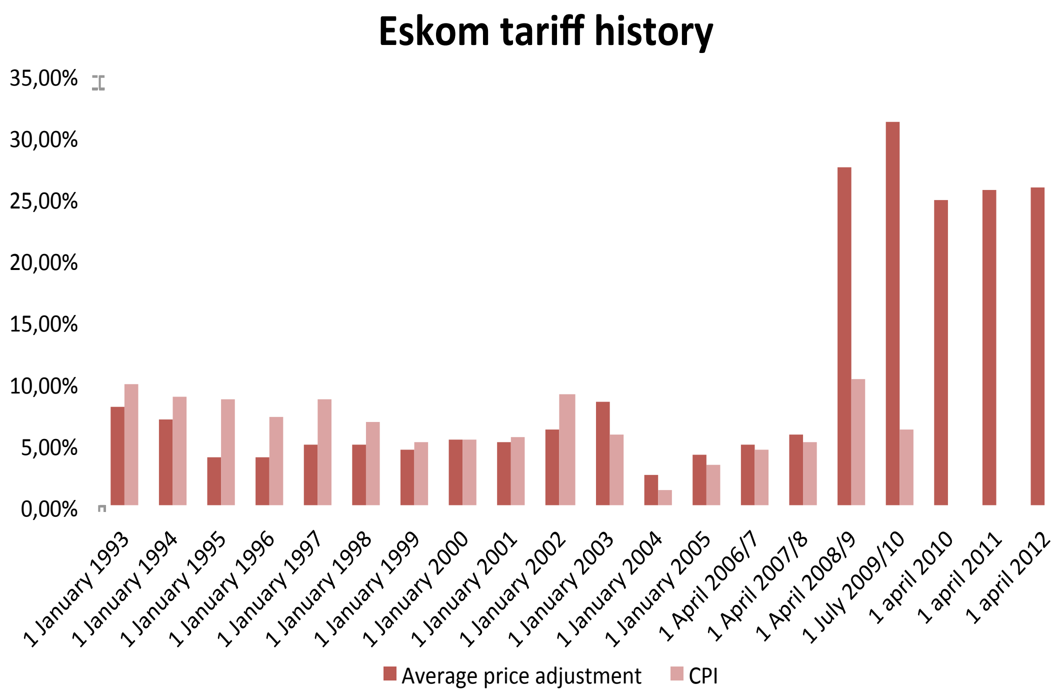


Figure 39: Eskom's electricity tariff history. Data adapted from (Eskom , 2012) (Hoops, 2010).

The price of electricity increased, on average, with 5,36% between 1993 and 2008. After that electricity prices increased rapidly between 2008 and April 2012. The overall average price adjustment was 10,79%.

Based on Figures 37 and 38 that represent the Gauteng petrol price increases and Figure 39 that illustrates Eskom's tariff price increase history, assumptions regarding the expected annual price increases are modelled in different scenarios in the TCO calculation. An overview of these assumptions is summed up in Table 19.

4.3.6 Total Cost of Ownership

According to Essen, Braat, Kampman and Gopalakrishnan (2011), the following aspects have to been taken into account to calculate the total cost of ownership:

1. Purchase cost of the vehicle, including taxes and subsidies.
2. Insurance cost.
3. In case of battery purchase: lifetime of the battery and, possibly, residual value.
4. Lifetime of the vehicle, or resale value after a certain number of years.
5. Fuel and/or electricity use per kilometre (in litre/km and kWh/km).
6. ICEVs will only use fuel, EVs only electricity but PHEVs and EREVs may use both, depending on the trip length and driving style.
7. Maintenance cost.
8. Tax related to car ownership.

Some of these aspects, such as insurance costs, the resale value and lifetime of the vehicle and battery, are not included in the calculation due to the fact that these figures are still uncertain for South Africa and can only be based on speculations. However, it is not expected that insurance costs of both vehicles would differ much (Harrop & Zervos, 2011).

In order to compare the cost of a newly bought EV and ICE vehicle the following assumptions were made.

EV: Nissan Leaf

- Not available yet in SA. Price based on European price
- Zero tax emission. Under 120g/km threshold
- 25 kWh battery pack
- 14560 km per annum

ICE: Volkswagen polo sedan 1.4 rendline

- Available in SA. Price based on SA market price
- Tax emission; acceding 120g/km threshold
- Engine comparable with Leafs electric motor and 25 kWh battery
- 14560 km per annum

Eight scenarios were modelled in order to identify the key variables that are affecting the total cost of ownership (TCO) and to see when, and if, EVs could potentially be less expensive to drive than ICE vehicles. The variables upon which the total costs of ownership are based on are:

Included

- Initial vehicle price
- Petrol and electricity price
- Forecasted annual Petrol/electricity price increase
- Maintenance costs
- Battery price
- Battery price reduction
- Possible governmental incentives

Excluded

- Insurance costs
- Resale value of vehicles
- Resale value of battery pack

To compare maintenance cost, figures (see Appendix B1) of a recent study (Essen, Braat, Kampman, & Gopalakrishnan, 2011) have been used.

Table 18 shows the total cost for both vehicles for the first year. CO_2 emission tax is paid once when the vehicle is purchased. To calculate the TCO in the absence of detailed sales figures for the Nissan Leaf, it is assumed that Nissan SA will introduce the Leaf at the same or similar price as it has done in Europe. In that case, the Nissan Leaf full electric vehicle would be priced at R 285,460.00 and would thus be R 125,560.00 (44%) more expensive then the Volkswagen Polo sedan 1.4 Trendline ICE vehicle.

Table 18: Cost comparison EV Nissan Leaf and ICE Volkswagen polo sedan 1.4 trendline 1st year

1st year	EV including Battery	ICE vehicle
Purchase cost of Vehicle	R 285,460.00	R 159,900.00
C02 emission Tax	R 0,00	R 2,250.00
Total cost of vehicle	R 285,460.00	R 162,150.00
Maintenance*	R 4,298.00	R 9,386.00
Fuel Cost	R 3,073.00	R 9,956.00
Total	**R 292,831.00**	**R 181,492,00**

* Source: (Essen, Braat, Kampman, & Gopalakrishnan, 2011)

Note that the following calculations comparisons are based on the purchase and operating cost for EVs and ICE vehicles per year. In other words, can owning and operating an EV be less costly compared to an ICE vehicle and if so in what year will this be based on the variables in the model as described below? The accumulated TCO over the period that the vehicle is owned between 2012 and 2031 will also be discussed in section 4.3.6.2 and is illustrated in Figure 48. Larger graph representations can be found in Appendix B3.

4.3.6.1 Annual total cost of ownership

The following scenarios are modelled to identify the major variables that can play a significant role in total cost of ownership of EV and ICE vehicles.

Table 19: Overview of scenario variables used for TCO calculation

Scenario	Annual electricity increase	Annual fuel increase	Annual battery decrease	Incentives first 5 years	Incentives every year	TCO EV lower then ICE
1	5,50%	5,50%	8%	-	-	2030
2	10%	10%	8%	-	-	2027
3	10%	10%	12%	-	-	2024
4	5,50%	10%	12%	-	-	2023
5	5,50%	10%	12%		11,793*	2021
6	5,50%	10%	12%	11,793		2023
7	20,00%	10%	12%	-	-	-
8	20,00%	10%	12%	11,793	-	-

* Incentive of R 11,793.00 based on the average EU and USA incentive

Table 19 shows the key variables that have been adjusted per scenario. Figures 40 and 41 are based on scenarios 1 and 2. In both cases, a decrease of 8% in battery costs is included. Fuel and electricity prices are kept the same with an increased rate of 5,50% per annum in the first, and 10% in the second scenario. The graphs below show a similar tendency, and what becomes clear is that fuel and electricity prices play an important role. Annual increases of 5,50% in both fuel and electricity prices show that the TCO of electric vehicles will only become lower in the year 2030. With an annual increase of 10% in both fuel and electricity prices, an electric vehicle will become cheaper in 2027.

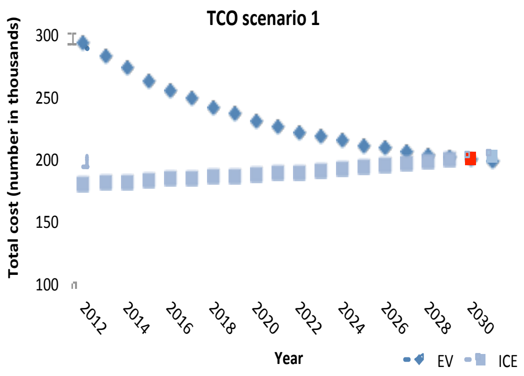


Figure 40: Total cost of ownership comparison based on scenario 1

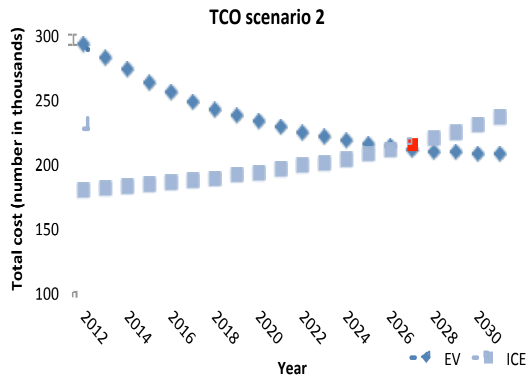


Figure 41: Total cost of ownership comparison based on scenario 2

The graphs represented in Figure 42 and 43 are based on scenarios 3 and 4. A decrease in battery costs of 12% and different annual fuel and electricity price increases have been taken into consideration. Outcomes from scenario 3 show that the TCO of an EV will become lower in 2024 compared to 2027 in scenario 2. Annual fuel/electricity prices have been kept the same and an increase of 4% in battery cost reduction, compared to scenario 2, results in a lower TCO in 3 years time.

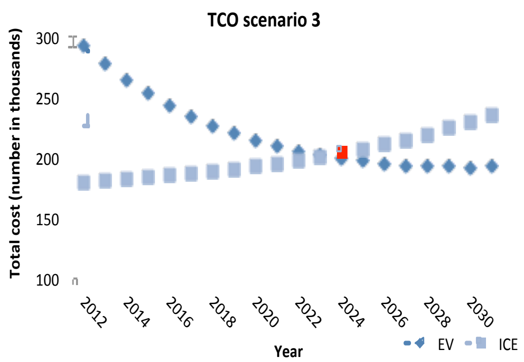


Figure 42: Total cost of ownership comparison based on scenario 3

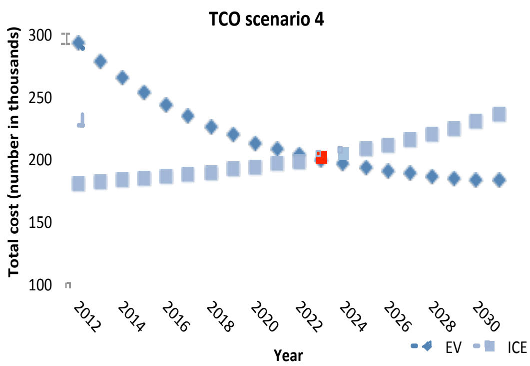


Figure 43: Total cost of ownership comparison based on scenario 4

Figures 44 and 45 represent scenarios 5 and 6. In these cases, annual fuel and electricity price increases are both the same with an electricity increase of 5,50% and 10% fuel increase, while battery costs reduce with 12% per annum. Scenario 5 has been modelled with the assumption that government will provide an incentive as proposed in the DTI key action plans. If this incentive of R 11,793 per year would be provided every year, the TCO of an electric vehicle will be lower than that of an ICE vehicle by 2021. Although it is highly unlikely that government will provide incentives over such a long period, it is more realistic that government will provide incentives for the first 5 years as represented in scenario 6 (see Figure 45) to stimulate consumer uptake and market penetration like it has been done in Europe and the U.S. and previously discussed and illustrated in paragraph 3.1

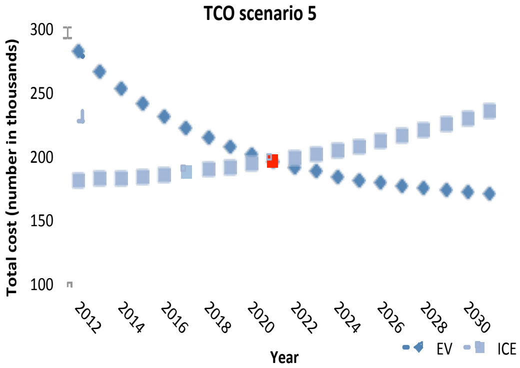


Figure 44: Total cost of ownership comparison based on scenario 5

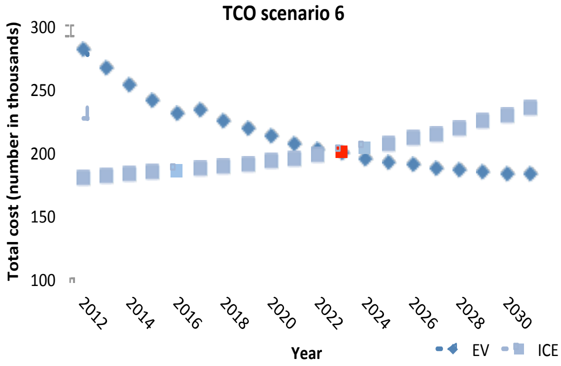


Figure 45: Total cost of ownership comparison based on scenario 6

In the case of an annual governmental incentive over a period of 5 years, EVs will become cheaper to drive and own then ICE vehicles in 2023.

The last two scenarios (see Figures 46 and 47) are modelled with a very steep annual electricity price increase and are based on the latest price increases that have been observed in South Africa and previously illustrated in Figure 39. When petrol prices would rise every year with a steady 10% and electricity prices with 20%, purchasing and driving an EV won't become cheaper (see Figures 46 and 47) than driving an ICE vehicle under the conditions that battery costs will drop with 12% per year. No matter what year the ICE vehicle and EV are purchased, the EV will be more expensive in that particular year. Even if governmental vehicle acquisition incentives would be introduced (see Figure 47) for the first 5 years, it will not make operating EVs more viable than ICE vehicles.

Electricity prices will rise over time and the DTI describes in their action plans for the electrical vehicle industry that they, together with the DoE and Eskom, are to formulate preferential electricity tariffs that provide incentives for EV users (DTI, 2011). Preferential electricity tariffs can significantly reduce EV operating costs in the future.

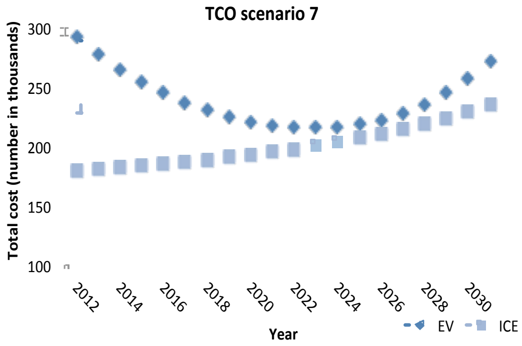


Figure 46: Total cost of ownership comparison based on scenario 7

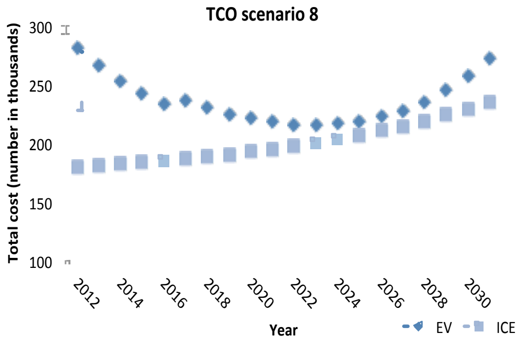


Figure 47: Total cost of ownership comparison based on scenario 8

4.3.6.2 Accumulated total cost of ownership

The accumulated total cost of ownership per scenario between 2012 and 2031 has also been modelled and is represented in Figure 48 (see also Appendix B3 for larger graph representations). These results show that the TCO of an ICE vehicle over this period, calculated from year of purchase until the year 2031, is in the first 6 scenarios higher compared to the TCO of electric vehicles. In scenario 3-6, the TCO of ICE's are twice as high, and in scenario 5 even higher.

When electricity prices increase with 20% per year (as has been observed in South Africa's electricity prices between 2008 and 2012), petrol with an average 10% per year and battery costs do not decline with more than 12% per year, EVs will only be cheaper to own and operate in the first 12 years compared to ICE vehicles according to scenario 7 and 8. After 2025, the accumulated TCO of an EV are higher under these conditions. Battery costs are reducing at a faster rate over the first years when the initial cost of a battery is higher. Eventually, the battery cost reduction is almost coming to a halt and high annual electricity price increases are exceeding the 12% battery cost reduction rate resulting in higher ownership and operating costs for EVs. The costs of a battery pack in 2025 under these conditions will be around R 24,630.00 and in 2031 R 11,438.00. A difference of R 13,192.00 while electricity prices increase over the same period from R 32,880.00 to R 98,18.00, and will thus be 3 times higher. Governmental incentives in the first 5 years don't make a significant difference although it will reduce initial costs in the first years. EVs will eventually be more expensive in due course under the described conditions for scenario 7 and 8, meaning that, even with governmental incentives, electric vehicles are not a viable alternative at present under these circumstances. Preferential electric tariffs, as proposed by the DoE and Eskom, can however have a positive effect on the TCO of EVs. With these sort of incentives the gap between fuel and electrify prices will become smaller and ultimately favouring electric vehicles operational costs. If this will make EVs more viable depends on the extent of incentives on electrify tariffs and future electricity and fuel prices. No data regarding these tariffs have been presented so far.

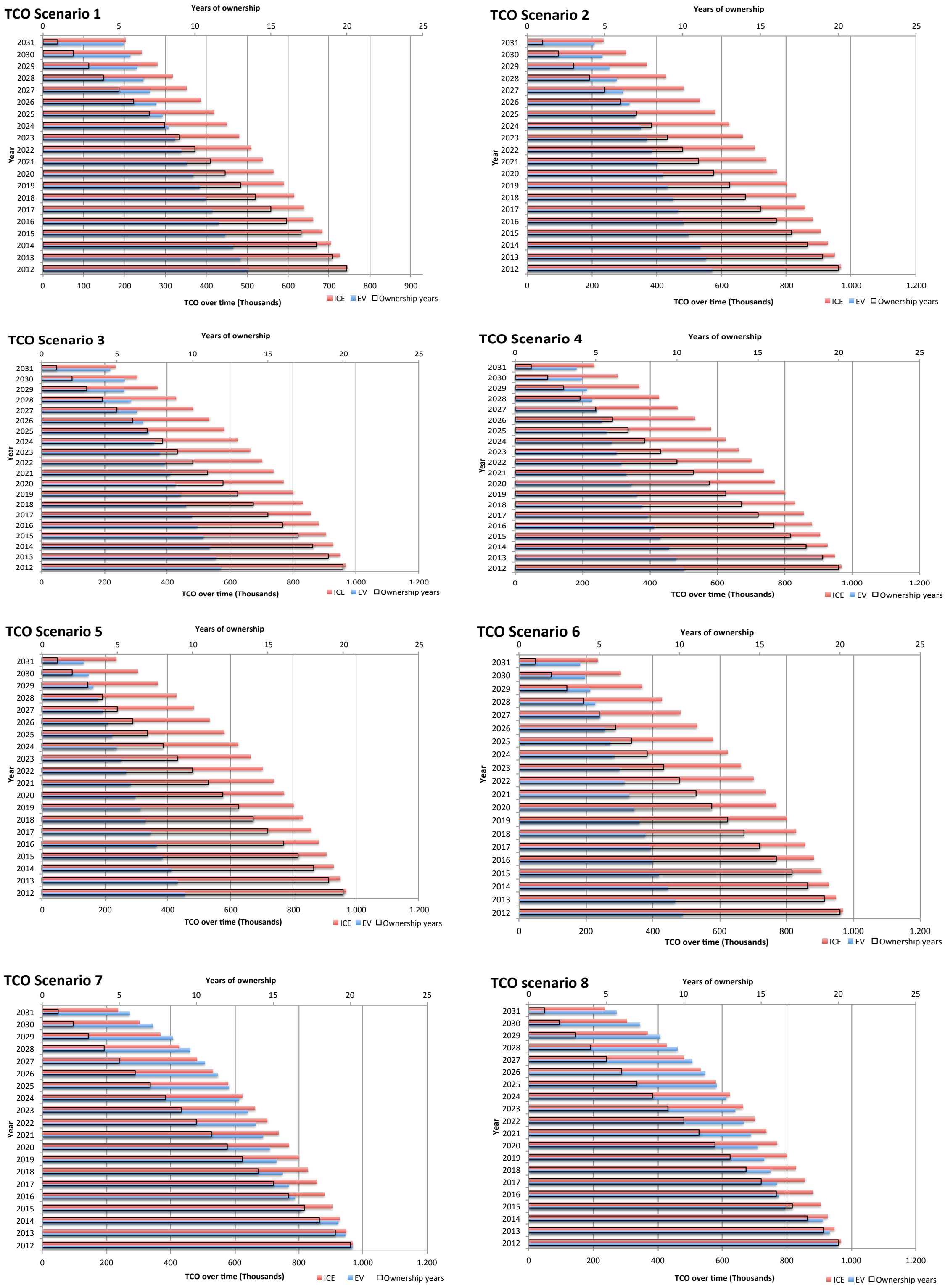


Figure 48: TCO scenarios comparison between electric and ICE vehicles accumulated overtime

The 8 scenarios prove that the two key variables identified in the total cost of ownership comparison of EV and ICE vehicles are fuel and electricity prices as well as battery cost and battery cost reduction.

4.3.6.3 Conclusion

A decrease in battery and vehicle price is crucial in order to make it more affordable to purchase electric vehicles. The scenarios that are based on an annual battery cost reduction of 8% are in line with the forecasts of the Deutsche Bank and the electrification roadmap from Coalition. Scenarios based on a 12% cost reduction rate are more optimistic but show the significance of battery cost reduction over time. When EVs will be cheaper to purchase depends primarily on the rate of battery cost reduction.

Fuel and electricity prices are the biggest variables in operating costs. Although future costs of both are somewhat uncertain, the scenarios have proven that ICE vehicles are more expensive then EVs over time if the same annual rates of electricity cost increases between 5,5% and 18% and petrol increases with 10% are taken into account. If electricity prices will see an annual percentage increase of 20% and higher, as was the case in the last 4 years, electric vehicle costs will not become cheaper than ICE vehicles and will likely not be picked over the favoured ICE vehicle as consumers do today. When electricity and fuel prices are compared with prices in different countries it is noticed that a big difference in price per energy source has a significant effect on the TCO.

In the Netherlands, for instance, electricity is sold for € 0,20 per kWh and a litre of unleaded petrol for € 1,80, whereas, at the moment, 1 kWh costs approximately € 0,12 and unleaded petrol € 1,12 per litre in South Africa. The difference between both energy sources in the Netherlands is thus € 1,60 and in South Africa € 1,00. The bigger the gap between energy prices (electricity being cheaper than petrol), the more economically viable it will be to drive EV vehicles. Thus, the annual travelled kilometres change the TCO of both propulsion systems since the difference between specific energy costs are 69% (based on current energy prices), as calculated in equation 1 and 3 on page 75.

Governmental incentives won't have much effect on the TCO of electric vehicles, contrary to what was expected, but it can have a psychological effect on consumers and, thus, can stimulate the uptake rate and market penetration which is very important if a rapid introduction and implementation of electric vehicles is desirable. Preferential electricity tariffs can however potentially lower operating costs of EVs. Fuel/electricity prices and the rate of battery cost reduction are the key factors that influence the total cost of ownership and viability of electric vehicles compared to ICE vehicles.

4.4 Strain on South Africa's electricity grid

The South African electricity grid has encountered many power problems resulting in downtime and outages. Power outages are common due to shortage of electricity but it doesn't concern a total shortage but a peak shortage. Figure 49 is adopted from a presentation given by Kobus Meiring and Diana Blake from Optimal Energy (Meiring & Blake, ￼ Transport in the 21st Century ELECTRIC VEHICLES , 2010) and shows electricity supply of a typical winter and summer day and a peak day in 2006.

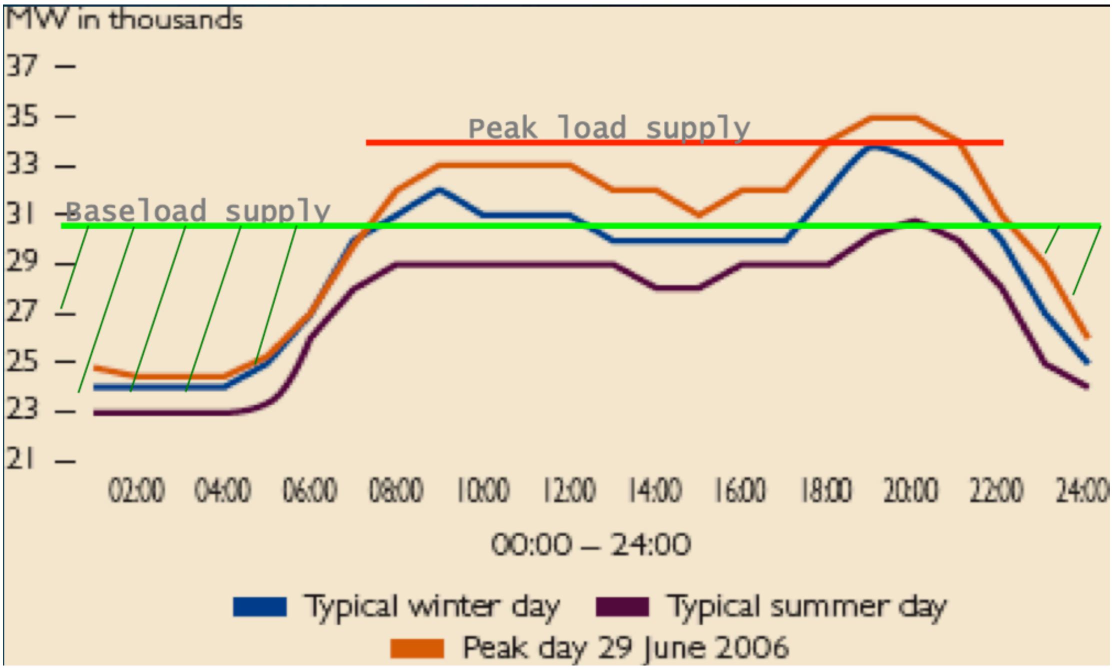


Figure 49: Electricity use in South Africa. Illustration adapted from (Meiring & Blake, ￼ Transport in the 21st Century ELECTRIC VEHICLES , 2010).

According to Meiring and Blake, there is enough electrical energy during off-peak hours for 8 million cars doing 20 000 kilometres per year while there are only 7 million cars in South Africa. Figure 49 shows that during a day there are 2 peaks in the electricity demand being between 5–9 am and 6-10 pm. This is a result of consumers switching on lights, taking showers, kitchen appliances and, occasionally, air conditioners or electric heaters during mornings and evenings. Between these peak periods, the strain on the grid stabilises out again. In the case of introduction of e-mobility in SA, electric vehicles should therefore be charged during off-peak periods preferable between 10 pm and 5 am. In this timeframe. the preferential electricity tariffs as proposed by the DoE and Eskom ought to be introduced.

Figure 50 illustrates the comparison between produced and consumed electricity in billion kWh's in South Africa between 2000 and 2011. Data acquired from Index mundi (2011).

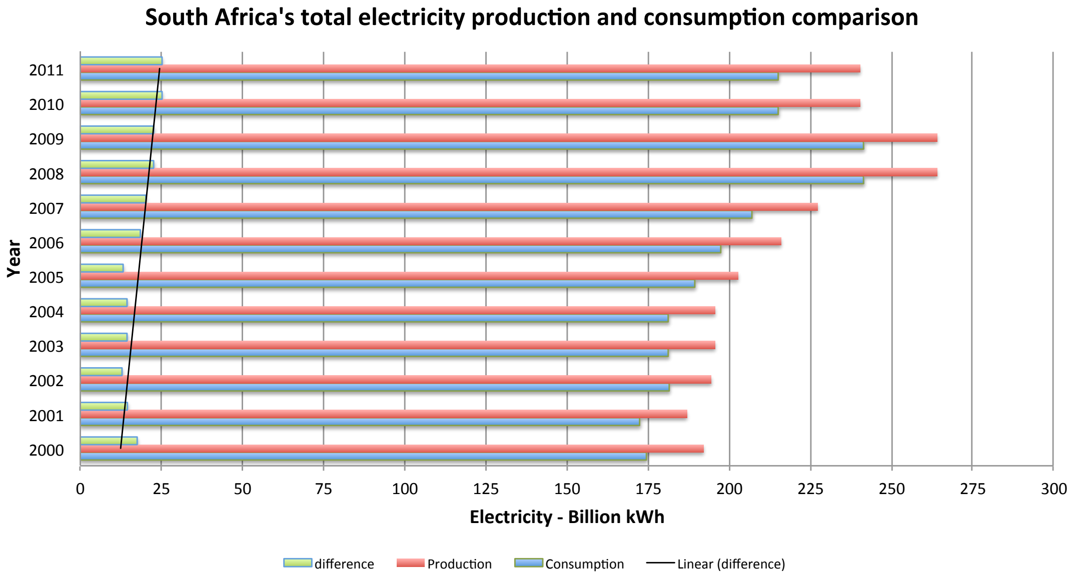


Figure 50: Electricity production and consumption comparison

The black line in Figure 50 represents the average difference between production and consumption. Over the past 10 years this average has increased and a total overproduction in 2011 of 25 billion kWh has been observed. According to (Mueller, 2012) this overproduction is a result of insufficient storage and users capacity during nighttime and occurs because shutting down and starting up electricity production is more costly then producing for the bin. Charging during off-peak hours produces no additional emissions since electricity is already produced but not being utilized. A recent study of Eskom stated that if EVs will see the utilization of 120 000 EVs (approximately 1,7 % of total vehicle fleet) as projected by the DTI that the impact on the grid would be less than 2%. According to a presentation of Meiring and Blake (2011) switching South Africa's fleet to ~ 10% electric vehicles would, essentially, save 1700 million litres of fuel and a net energy saving of ~12 000 GWh. South Africa's national target is to save 10 000 GWh by 2013. Converting South Africa's fleet to ~ 10% electric vehicles will consequently reduce oil dependency and result in energy saving.

A pilot project to monitor electricity usages to assess the effectiveness of new load limiting technology has been implemented in the Gauteng province by Eskom DSM in conjunction with Eskom Research and Innovation Department (ERID) and EON consulting. A free display instrument called the eddi is installed at participants and, according to Eskom, displays the real-time demand of the various electrical appliances at work in his or her individual household (Eskom, 2011). In addition, the system can be used to limit the supply to participating households when there is a constraint on the national grid. By stabilizing the electricity network through load limits, load shedding can be avoided. Controlling demand via load limiting technology is a practical and feasible alternative to load shedding (black outs) according to Eskom (2011).

5 CHAPTER FIVE – CONCLUSIONS AND RECOMMENDATIONS

5.1.1 Requirements for South Africa in order to introduce e-mobility

At present there is no charging infrastructure in place and home charging equipment is not yet commercially available. It is most likely that, in the future, after the introduction of PHEVs and full EVs in the automotive market, drivers will charge their vehicles at level 2 charging at home over night during off-peak hours.

If in the future a network for public charging is to be developed, a high density of charging points is required to initiate the uptake of EVs and reduce range anxiety. This density and availability can be reduced over time by the introduction of better battery specifications and sizes which would result in shorter and less frequent charging times. As mentioned before, level 2 charging will be preferential for early adopters and home chargers will become more widely available and, with that, prices will decrease as well. It has been observed that acquisition incentives have almost no effect on the TCO of EV's but preferential electricity tariff incentives as proposed by the DTI, however, can be an enormous support for EV drivers and therefore for the whole e-mobility sector. Electricity is overproduced during night hours while most of the population has no need for electricity. With this unutilized energy 8 million cars doing 20 000 kilometres per year can be charged with minimal impact on the grid. Charging EVs with this extra electricity is thus eminently the best option without straining the grid.

Charging through inductive coupling (wireless) is a great technique and improves city aesthetics but requires the most expensive infrastructure. Wireless charging won't be a viable charging solution to introduce e-mobility in South Africa. With fast charging (level 3), vehicles can be charged from empty up to 80% in less than 10 minutes and refuelling times will then be comparable with those of ICE vehicles. However, level 3 charging at the moment is still not a stable way of charging and causes the battery to heat up rapidly, which reduces the lifetime. Wolkin (2009) stated that fast charging will have an adverse impact on the grid if it were mass deployed. For example, charging a 25 kWh battery in 5 minutes would require over 300 kW power; to put this in perspective, two cars fast charging at the same time would be equal to the power feed of an average office building. This will result in a tremendous strain on the South African power grid.

Better Place provides a service that swaps depleted batteries for checked, maintained and recharged batteries. According to this model, swapping stations are to be constructed throughout the country and can be seen as a drive through facility where a battery is swapped in less than 1 minute. From a technical point of view, Better Place's business model can't work due to the lack of international vehicle and battery developing standards. Not many EVs or PHEVs have been developed yet but those who are available all have different battery specifications and sizes (see Figures 51 en 52).

Figure 51: The T-shaped battery pack of the GM Volt

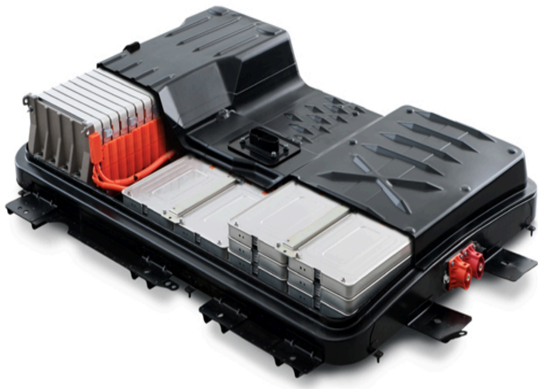


Figure 52: Battery pack of the Nissan Leaf

It's doubtful that swapping stations will carry vast battery model inventories. The automotive and battery developers have to together with the government find a way to standardize size, shape and specifications for a business model like this to work.

Battery cost has proven to be one of the costliest aspects of electric transportation. The battery forms almost 50% of the total cost of an EV and its reliability and degradation rate is still uncertain. For electric vehicles to make a significant introduction in the automotive market in South Africa, business models that are based on model 2 (as discussed in paragraph 4.2) should be considered.

Due to this high battery and vehicle cost, potential excessive electricity price increases in the future and the absence of a charging infrastructure in South Africa introducing e-mobility on a model 1 based business model won't be viable at present. When petrol prices increase every year with a steady 10% and electricity prices will see an annual percentage increase of 20% and higher, such as observed in the last 4 years, purchasing and driving an EV won't become cheaper than driving an ICE vehicle under the conditions that battery costs will drop with 12% per year. At what stage EVs will be cheaper to purchase depends primarily on the rate of battery and vehicle cost reduction while decrease in operating costs relies predominately on the difference in fuel/electricity prices.

Given all the information available at the moment there are too many uncertainties regarding the technical side and too little data on the economical/financial side of e-mobility. In order to acquire this data, demonstration projects to facilitate future e-mobility are to be commenced. Stellenbosch can be a good location for a small-scaled demo project and will be less costly than starting a demonstration project in bigger areas such as the Cape metropolitan or Gauteng area. Vital information regarding charging needs and habits will be gathered and results and ideas can be compared to similar demonstration plans around the globe and used for benchmarking purposes.

The data gathered from such a project include:

- Frequency of charging
- Charging preferences
- Charging location
- Impact on grid
- Charging time
- Average km travelled
- Average speed
- Range evaluation
- Usage area
- Fuel/electricity consumption
- Driving style impact on battery
- Battery performance and degradation rate
- Operation costs (cost per km)
- Initial costs (purchasing cost)
- Maintenance costs
- ROI

Stellenbosch transport patterns have been modelled by Crous (2010) and results are shown in the table and figures below. On average, trip lengths for the three income groups of people who are employed in the Stellenbosch area are between 8.1 and 8.6 km per day (see Table 20).

Table 20: Average commuter trip lengths (Stellenbosch municipality, 2010)

Income Group	Average Trip Length Stellenbosch Residents	Average Trip Length Cape Metropolitan Area
Higher Income	8.1 km	11.8 km
Lower Middle Income	8.8 km	13.8 km
Low Income	8.6 km	16.2 km

The numbers in the table above correspond only with km travelled by people who are employed in the Stellenbosch area. Unemployed and students have not been taken into account.

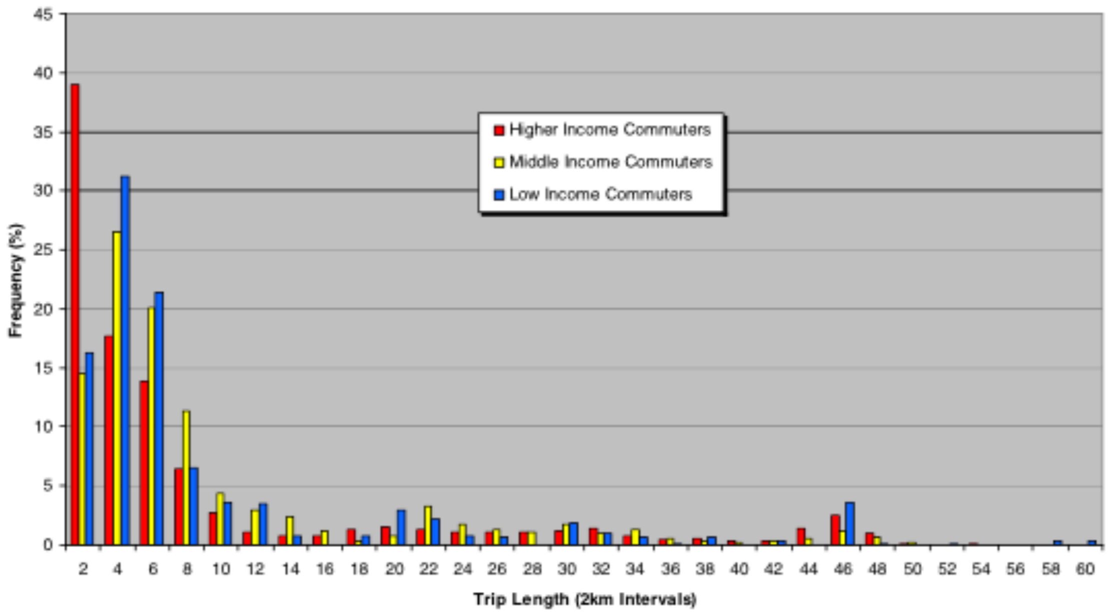


Figure 53: Trip length frequencies for Stellenbosch residents. Illustration adapted from (Crous, 2010)

Figure 53 represents the frequency and trip length of Stellenbosch residents in all three-income levels. The majority travels between 2 and 10 kilometres per day. Figure 54 shows the trip length frequency of the three income levels of Stellenbosch employees. In this case there are two peaks noticed between 2-10 km and 18–28 km per day.

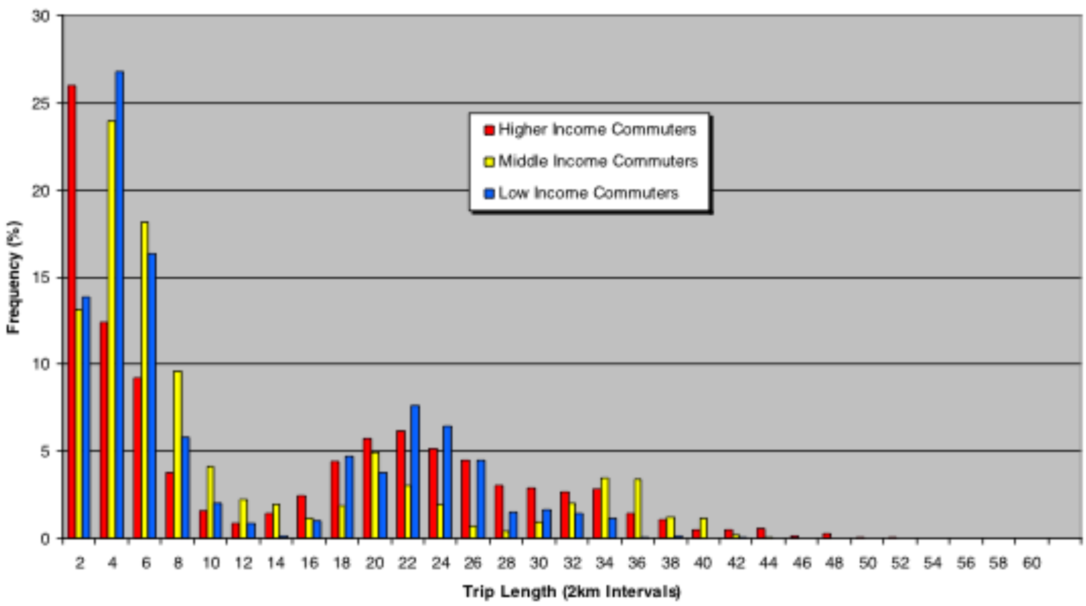


Figure 54: Trip length frequencies for Stellenbosch employees. Illustration adapted from (Crous, 2010)

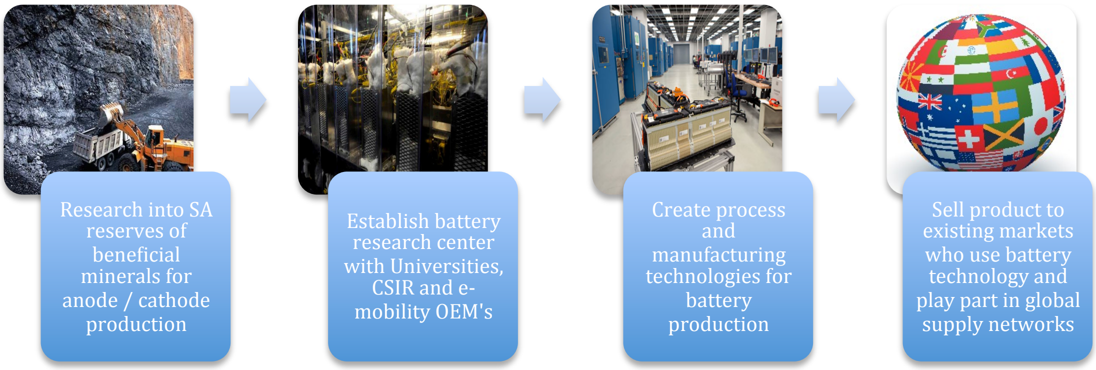
Based on Figures 53 and 54 it is clear that the Stellenbosch residents and employees don't travel on average more than the range that an available electric vehicle provides at

present. The average trip length is a reason why Stellenbosch is a suitable place for a demonstration project. As the average trip length is shorter than in larger areas such as Gauteng where people might have to travel longer to get to their destinations, the EVs can be used per day by more participants and this provides more detailed information about different driving styles/habits. The introduction of a demonstration project in Stellenbosch based on car sharing clubs will in the authors view be the best way to gather viable insights. Car clubs have proven to be an excellent alternative for vehicle and electric vehicle use in Europe and the U.S. car sharing clubs make use of sharing programs. Vehicles can be parked almost everywhere throughout the Stellenbosch region and registered members can make use of a pay as you go system. By logging into the car sharing website, consumers can specify what type of car they would like to use and for what time and what the charged status is and if that would be sufficient for their trip. With the digital advances on hand, it is possible for consumers to get access to vehicles with a key card or USB key for the period that the car has been reserved and paid. By introducing car sharing clubs and keeping costs low, Stellenbosch students and residents will then have the opportunity to hire an EV to get around in the area for a relatively small fee (how high this fee will be depends mainly on the amount of governmental and public/corporate investments). Tracking of these vehicles in the Stellenbosch region will provide crucial information for vehicle and infrastructural developers and electricity distributors and other corporate/public sector or governmental bodies participating in the e-mobility value chain about driving patters, charging regularities and preferences. This would be the most suitable way in order to slowly introduce EVs in the South African market. After “closed system” demo projects and the data that has been gathered, implementation in larger areas can be researched.
With no infrastructure in place yet in South Africa and not everybody having access to indoor parking at home to recharge the used vehicle, the vehicle has to be returned to a certain parking where it is checked and recharged and these charging costs will be added to the costumers monthly bill. These parking facilities can be situated in cities, airports or established vehicle renting companies. After getting used to electrified transportation through car sharing models, vehicle or battery leasing models which lowers financial risk, can slowly take over now that consumers are more aware, but only if the needed infrastructure is developing with it at the same rate as is the case in Oregon for instance.

To support the learning process, a DoE Office of Electric Transportation should be responsible for collecting, organizing, and distributing all of the data regarding the operation of EVs such is done by the C2ES in 8 states in America being Arizona, California, Georgia, North Carolina, Ohio, Oregon, Washington, and Wisconsin (Centre for Climate and Energy Solutions, 2011). The government should also fund the direct costs of data collection activities incurred by non-governmental entities. The data should then be made public so that industry participants and researchers can examine it in order to better understand the challenges of electrified transportation and how to overcome those challenges.

In conclusion, if South Africa is to introduce electrified transportation it must be on a model 2 based business model to potentially be viable. Electricity tariff incentives, EV leasing and sharing clubs will reduce the total cost of ownership of electric vehicles, raise consumer awareness and give more insight in charging needs and infrastructural requirements. Viability is to be proven through demonstration project. If a model 2 based business model proves to be viable, South Africa can research model 1 possibilities in the future when battery and vehicle prices have diminished. The proposed governmental incentives (estimated to be equivalent to European incentives) won't have much effect on the TCO and will not make EVs more viable then ICE vehicles but a push from government is necessary to initiate e-mobility. Preferred electricity tariff schemes for EV owners will reduce operational costs and can be supported by government.

Furthermore, local battery production and the commodities required for this production should be researched. Commodities such as lithium are not too common in South Africa, but are more readily available in the Americas. The estimated lithium resources in South Africa are between 1,000 and 3,000 tons (DTI, 2011). A study appointed by the Industrial Development Corporation (IDC) has found that certain minerals that are beneficial for cathode, anode and electrolytes (battery development required components) may offer the greatest potential for localization in South Africa. It is, therefore, recommended that more research be conducted into the quantities of minerals that South Africa has in reserve that can be used for battery and battery component production. South Africa should create a battery research centre in cooperation with universities, e-mobility OEMs and the CSIR in order to invest in the potentials of local battery or battery components production and play a part in the global supply network as described in the following diagram.



5.1.2 Other recommendations and future work

- The government has to establish a committee to create developing and safety aspects standards.

- In the case of e-mobility introduction, the feasibility of equipping public parking places with solar panel shadings should be researched. Potential EV drivers in the SA market can then recharge their car during peak hours without creating a strain on the grid and can do this without having access to covered/indoor parking facilities.

- Stellenbosch University should establish a 'think tank' with Optimal Energy, the City of Cape Town, and the Department of Transportation, regarding the production of drivetrain and propulsion specifics for the proposed e-busses in Cape Town.

- The potential market for two wheeler e-bikes has to be researched as it has been proven to be a big market for Europe and China.

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APPENDIX

A1: List of globally available HEV/PHEV/ EVs.

Source: (Lache, Galves, & Nolan, 2009)

3 November 2009 Autos & Auto Parts Electric Cars: Plugged In 2 Deutsche Bank

Figure 1: Hybrid (HEV), Plug-in Hybrid (PHEV), and Electric (EV) Models by year (HEV unless otherwise indicated)

2008 (13 Models)	2009 (29 Models)	2010 (61 Models)	2011 (98 Models)		2012 (119 Models)	
Ford Escape	Ford Escape	Ford Escape	Ford Escape	BMW 3 Series	Ford Escape	BMW 3 Series
GM Lg SUV's	GM Lg SUV's	GM Lg SUV's	GM Lg SUV's	BMW 5 Series	GM Lg SUV's	BMW 5 Series
GM Malibu	GM Malibu	GM Malibu	GM Malibu	Daimler C-Class	GM Malibu	Daimler C-Class
Honda Civic	Honda Civic	Honda Civic	Honda Civic	Daimler B-Class [EV]	Honda Civic	Daimler B-Class [EV]
Nissan Altima	Nissan Altima	Nissan Altima	Nissan Altima	Dongfeng Aeolus	Nissan Altima	Dongfeng Aeolus
Toyota Prius	Toyota Prius	Toyota Prius	Toyota Prius	Ford Flex	Toyota Prius	Ford Flex
Toyota Camry	Toyota Camry	Toyota Camry	Toyota Camry	Ford Focus [EV]	Toyota Camry	Ford Focus [EV]
Toyota Highlander	Toyota Highlander	Toyota Highlander	Toyota Highlander	GM Mid CUV's	Toyota Highlander	GM Mid CUV's
Toyota Estima	Toyota Estima	Toyota Estima	Toyota Estima	GM Sm CUV's	Toyota Estima	GM Sm CUV's
Toyota Crown	Toyota Crown	Toyota Crown	Toyota Crown	GM Lg Sedan	Toyota Crown	GM Lg Sedan
Toyota Lexus GS	Toyota Lexus GS	Toyota Lexus GS	Toyota Lexus GS	GM Volt [PHEV]	Toyota Lexus GS	GM Volt [PHEV]
Toyota Lexus RX	Toyota Lexus RX	Toyota Lexus RX	Toyota Lexus RX	GM Small CUV [PHEV]	Toyota Lexus RX	GM Small CUV [PHEV]
Toyota Lexus LS	Toyota Lexus LS	Toyota Lexus LS	Toyota Lexus LS	Honda Acura RL	Toyota Lexus LS	Honda Acura RL
	BYD E6 [EV]	BYD E6 [EV]	BYD E6 [EV]	Honda Odyssey	BYD E6 [EV]	Honda Odyssey
	BYD F3DM	BYD F3DM	BYD F3DM	Hyundai Tucson	BYD F3DM	Hyundai Tucson
	Changan Jiexun	Changan Jiexun	Changan Jiexun	Mitsubishi Colt	Changan Jiexun	Mitsubishi Colt
	Daimler S-Class	Daimler S-Class	Daimler S-Class	Nissan Serena	Daimler S-Class	Nissan Serena
	Ford Fusion	Ford Fusion	Ford Fusion	Nissan Infiniti M	Ford Fusion	Nissan Infiniti M
	Honda Insight	Honda Insight	Honda Insight	Nissan Fuga	Honda Insight	Nissan Fuga
	Hyundai Elantra	Hyundai Elantra	Hyundai Elantra	Nissan Van [EV]	Hyundai Elantra	Nissan Van [EV]
	Jianhuai Yuebin	Jianhuai Yuebin	Jianhuai Yuebin	Peugeot 3008	Jianhuai Yuebin	Peugeot 3008
	Mitsubishi iMiEV [EV]	Mitsubishi iMiEV [EV]	Mitsubishi iMiEV [EV]	Peugeot 408	Mitsubishi iMiEV [EV]	Peugeot 408
	Subaru Stella [PHEV]	Subaru Stella [PHEV]	Subaru Stella [PHEV]	Renault Kangoo [EV]	Subaru Stella [PHEV]	Renault Kangoo [EV]
	Tata Indica [EV]	Tata Indica [EV]	Tata Indica [EV]	SAIC Roewe 750	Tata Indica [EV]	SAIC Roewe 750
	Tesla Roadster [EV]	Tesla Roadster [EV]	Tesla Roadster [EV]	Subaru Legacy	Tesla Roadster [EV]	Subaru Legacy
	Tianjin Messenger [EV]	Tianjin Messenger [EV]	Tianjin Messenger [EV]	Th!nk Ox [EV]	Tianjin Messenger [EV]	Th!nk Ox [EV]
	Th!nk City [EV]	Th!nk City [EV]	Th!nk City [EV]	Toyota Avalon	Th!nk City [EV]	Toyota Avalon
	Toyota Lexus H	Toyota Lexus H	Toyota Lexus H	Toyota Tundra	Toyota Lexus H	Toyota Tundra
	Toyota Lexus H	Toyota Lexus H	Toyota Lexus H	Toyota Tundra	Toyota Lexus H	Toyota Tundra
	Zotye Auto [EV]	Zotye Auto [EV]	Zotye Auto [EV]	Toyota Sequoia	Zotye Auto [EV]	Toyota Sequoia
		Bestrun B50	Bestrun B50	Toyota RAV4	Bestrun B50	Toyota RAV4
		BMW X6	BMW X6	Toyota Yaris	BMW X6	Toyota Yaris
		BMW 7-Series	BMW 7-Series	Toyota Lexus ES	BMW 7-Series	Toyota Lexus ES
		BMW Mini-E [EV]	BMW Mini-E [EV]	Toyota [PHEV]	BMW Mini-E [EV]	Toyota [PHEV]
		BYD F6DM [PHEV]	BYD F6DM [PHEV]	VW Polo	BYD F6DM [PHEV]	VW Polo
		Chery Qilin M1	Chery Qilin M1	VW Touareg	Chery Qilin M1	VW Touareg
		Chrysler Ram	Chrysler Ram	Volvo C30 [EV]	Chrysler Ram	Volvo C30 [EV]
		Chrysler Mid SUV	Chrysler Mid SUV		Chrysler Mid SUV	BMW MegaCity [EV]
		Chrysler / Fiat [EV]	Chrysler / Fiat [EV]		Chrysler / Fiat [EV]	Changan EV [EV]
		Coda Sedan [EV]	Coda Sedan [EV]		Coda Sedan [EV]	Chery ZC7050A [EV]
		Daimler M-Class	Daimler M-Class		Daimler M-Class	Chrysler / Fiat [EV]
		Daimler E-Class	Daimler E-Class		Daimler E-Class	Daimler Smart Fortwo [EV]
		Fisker Karma [PHEV]	Fisker Karma		Fisker Karma	Fisker Nina [PHEV]
		Ford Taurus	Ford Taurus		Ford Taurus	Ford Escape [PHEV]
		Ford Edge	Ford Edge		Ford Edge	GM / Reva JV [EV]
		Ford Transit Connect [EV	Ford Transit Connect [EV]		Ford Transit Connect [EV]	Hyundai [PHEV]
		Geely EK-1 [EV]	Geely EK-1 [EV]		Geely EK-1 [EV]	Nissan Infiniti [EV]
		Great Wall Oula [EV]	Great Wall Oula [EV]		Great Wall Oula [EV]	Peugeot [PHEV]
		Honda CR-z	Honda CR-z		Honda CR-z	Renault City [EV]
		Honda Fit	Honda Fit		Honda Fit	SAIC Roewe [PHEV]
		Hyundai Sonata	Hyundai Sonata		Hyundai Sonata	Tesla Model S [EV]
		Hyundai Accent	Hyundai Accent		Hyundai Accent	Toyota [EV]
		Kia Lotze	Kia Lotze		Kia Lotze	VW Porsche Cayenne
		Lifan 320 [EV]	Lifan 320 [EV]		Lifan 320 [EV]	VW Porsche Panamera
		Nissan Leaf [EV]	Nissan Leaf [EV]		Nissan Leaf [EV]	VW Passat
		Peugeot Ion [EV]	Peugeot Ion [EV]		Peugeot Ion [EV]	VW Up [EV]
		Peugeot Berlingo [EV]	Peugeot Berlingo [EV]		Peugeot Berlingo [EV]	VW Audi Sport [PHEV]
		Renault Fluence [EV]	Renault Fluence [EV]		Renault Fluence [EV]	Volvo V70 [PHEV]
		Tata Nano [EV]	Tata Nano [EV]		Tata Nano [EV]	
		Tianjin Siabao [EV]	Tianjin Siabao [EV]		Tianjin Siabao [EV]	
		Toyota Corolla	Toyota Corolla		Toyota Corolla	
		Toyota Auris	Toyota Auris		Toyota Auris	
		Toyota Sienna	Toyota Sienna		Toyota Sienna	
		VW Golf [PHEV]	VW Golf [PHEV]		VW Golf [PHEV]	

Source: Deutsche Bank compilation from various news sources, company press releases, JD Power, Ward's Automotive, just-auto.com

A2: list of EV/PHEV manufacturers and partnering battery manufactures with production targets where available

Source: (IEA, 2011)

Table 5A: Manufacturers of EVs/PHEVs and partnering battery manufacturers, with production targets where available

Car manufacturer	Announced/reported production/sales targets	Battery manufactures (may contains development partners and former partnership)
Daimler	10 000 in 2013 (5)	Johnson Controls-Saft (JCS), Sanyo, SK Innovation, Li-Tec Battery
Fisker	50 000 in 2013 (1) 85 000 in 2014	A123 Systems
Ford	18 000 in 2012 21 000 in 2013	LGChem, JCS, MAGNA E-Car Systems, Toshiba, Sanyo
General Motors	120 000 in 2012 (1)	LG Chem, JCS
Mitsubishi	40 000 in 2012 (2) 5% in 2015 20% in 2020	GS Yuasa Corporation, Lithium Energy Japan, Toshiba
Nissan	50 000 in 2010 in Japan 150 000 in 2012 in United States 50 000 in 2013 in United Kingdom	AESC
PSA	40 000 in 2014 (4)	Lithium Energy Japan, GS Yuasa, JCS
Renault	250 000 in 2013	AESC, LG Chem, SB Limotive (SBL)
Tesla	10 000 in 2013 (1) 20 000 in 2014	Panasonic Energy Company
Th!nk	10 000 in 2013 (1) 20 000 in 2014	A123 Systems, Enerdel, FZ Sonick
Volkswagen	3% in 2018 (3)	Sanyo, Toshiba, SBL,Varta Microbattery
BMW		SBL, E-One Moli Energy
BYD Auto		BYD group
Chrysler-Fiat		SBL, LG Chem
Coda Automotive		Coda Battery Systems
Hyundai		LG Chem, SBL, HL Green Power, SK Innovation
SAIC		JCS
Magna		GS Yuasa Corporation
Subaru		AESC
Suzuki		Sanyo
Tata		Electrovaya,EIG
Toyota		Primearth EV Energy, Sanyo
Volvo		EnerDel, LG Chem

(1) www.energy.gov/media/1_Million_Electric_Vehicle_Report_Final.pdf.
(2)www.mitsubishi-motors.com/publish/pressrelease_en/corporate/2011/news/detail0771.html.
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(5) www.bloomberg.com/apps/news?pid=20601100&sid=aT_u.QS7Y4tg.
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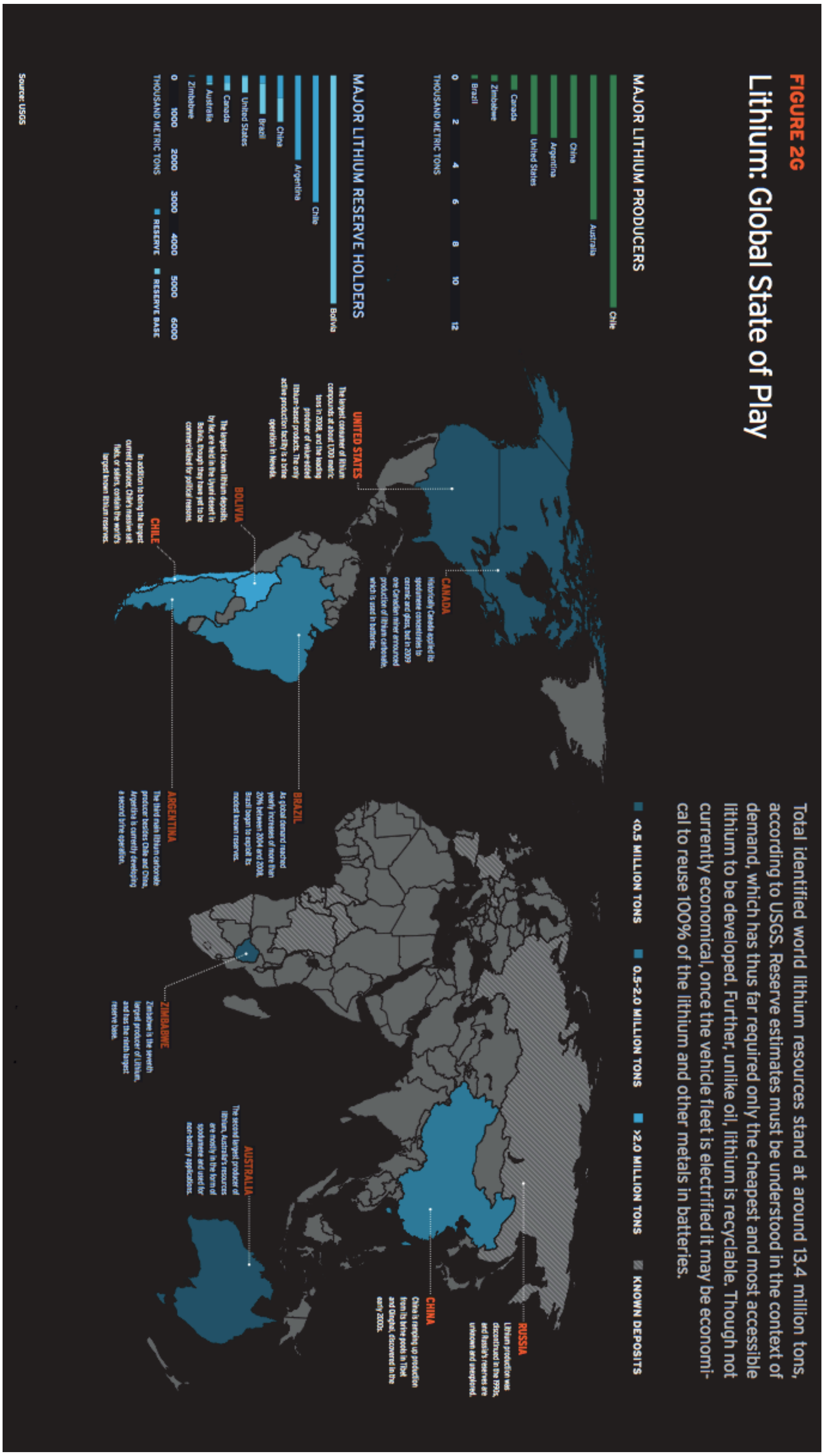
Sources: Various, updated by IEA May 2010.

A3: Overview of global lithium producers and reserve holders

Source: (Electrification Coalition, 2009)



A4: Example of incentives calculation in Denmark

Source: (Danish Ministry of Taxation, 2011)

The example below shows the calculation of registration tax for a passenger car whose street price in 2007 was DKK 227,000.

		Full rate 2007	
			DKK
Car price before registration tax			
Supplier sales price ex. VAT			85,000
VAT of 25%			21,250
Car price including VAT	(1)		106,250
Allowance in taxed value			
Radio	(1)		1,000
ABS	yes		3,750
ESP	yes		2,500
Taxed value	(2)		99,000
Registration tax			
Tax on value (2) exceeding DKK 76,400		180.00 %	40,680
Tax on value (2) under DKK 76,400		105.00 %	80,220
Tax allowance			
- Seatbelt alarms	3		- 300
Total registration tax	(3)		116,600
Street price of the car, ex. delivery costs (1) + (3)			**222,850**

B1: Maintenance cost figures used for TCO calculation

	Type	Size	Fuel	2010	2015	2020	2025	2030	Based on
Maintenance costs (€/year)	ICE	Small		457	504,56	557,08	615,06	679,08	CE Delft data
	ICE	Medium		914	1009,13	1114,16	1230,12	1358,16	CE Delft data
	ICE	Large		1396	1541,30	1701,72	1878,83	2074,38	CE Delft data
	PHEV	Small		209	230,75	254,77	281,29	310,56	Based on ICEs, differentiated to size/cost ratio
	PHEV	Medium		418	461,51	509,54	562,57	621,13	Based on ICEs, differentiated to size/cost ratio
	PHEV	Large		628	693,36	765,53	845,21	933,17	Based on ICEs, differentiated to size/cost ratio
	EREV	Small		209	230,75	254,77	281,29	310,56	Based on ICEs, differentiated to size/cost ratio
	EREV	Medium		418	461,51	509,54	562,57	621,13	Based on ICEs, differentiated to size/cost ratio
	EREV	Large		628	693,36	765,53	845,21	933,17	Based on ICEs, differentiated to size/cost ratio
	EV	Small		209	230,75	254,77	281,29	310,56	Based on ICEs, differentiated to size/cost ratio
	EV	Medium		418	461,51	509,54	562,57	621,13	Based on ICEs, differentiated to size/cost ratio
	EV	Large		628	693,36	765,53	845,21	933,17	Based on ICEs, differentiated to size/cost ratio
Insurance costs (€/year)	ICE	Small		620	685	756	834	921	CE Delft data
	ICE	Medium		1,240	1,369	1,512	1,669	1,843	CE Delft data
	ICE	Large		1,958	2,162	2,387	2,635	2,909	CE Delft data
	PHEV	Small		975	1,076	1,189	1,312	1,449	Based on ICEs, differentiated to size/cost ratio
	PHEV	Medium		1,949	2,152	2,376	2,623	2,896	Based on ICEs, differentiated to size/cost ratio
	PHEV	Large		2,924	3,228	3,564	3,935	4,345	Based on ICEs, differentiated to size/cost ratio
	EREV	Small		975	1,076	1,189	1,312	1,449	Based on ICEs, differentiated to size/cost ratio
	EREV	Medium		1,949	2,152	2,376	2,623	2,896	Based on ICEs, differentiated to size/cost ratio
	EREV	Large		2,924	3,228	3,564	3,935	4,345	Based on ICEs, differentiated to size/cost ratio
	EV	Small		975	1,076	1,189	1,312	1,449	Based on ICEs, differentiated to size/cost ratio
	EV	Medium		1,949	2,152	2,376	2,623	2,896	Based on ICEs, differentiated to size/cost ratio
	EV	Large		2,924	3,228	3,564	3,935	4,345	Based on ICEs, differentiated to size/cost ratio

Source: (Essen, Braat, Kampman, & Gopalakrishnan, 2011)

B2: Data used for TCO calculations

Scenario 1

Year	Fuel cost	kWh/year	Fuel cost	litres/year	Battery	Maintenance		Total costs	
Scenario 1	EV	2519	ICE	859	EV	EV	ICE	EV	ICE
2012	1,22	3.073,18	11,59	9.955,81	129.779,32	4.283,10	9.784,35	292.816,28	179.640,16
2013	1,29	3.242,20	12,23	10.503,38	118.964,42	4.447,66	9.989,82	282.334,97	180.393,20
2014	1,36	3.420,53	12,90	11.081,07	109.050,76	4.618,55	10.199,61	272.770,51	181.180,67
2015	1,43	3.608,66	13,61	11.690,52	97.334,49	4.796,00	10.408,00	261.419,82	181.998,52
2016	1,51	3.807,13	14,36	12.333,50	89.645,07	4.877,53	10.604,29	254.010,41	182.837,80
2017	1,59	4.016,52	15,15	13.011,85	82.563,11	4.960,45	10.804,29	247.220,76	183.716,14
2018	1,68	4.237,43	15,98	13.727,50	76.040,62	5.044,78	11.008,06	241.003,51	184.635,56
2019	1,77	4.470,49	16,86	14.482,51	70.033,41	5.130,54	11.215,67	235.315,12	185.598,18
2020	1,87	4.716,37	17,79	15.279,05	64.500,77	5.250,00	11.491,00	230.147,82	186.670,05
2021	1,98	4.975,77	18,77	16.119,39	59.405,21	5.349,07	11.707,84	225.410,73	187.727,23
2022	2,08	5.249,44	19,80	17.005,96	54.712,20	5.450,00	11.928,76	221.092,32	188.834,72
2023	2,20	5.538,15	20,89	17.941,29	50.389,94	5.552,85	12.153,86	217.161,61	189.995,15
2024	2,32	5.842,75	22,03	18.928,06	46.409,13	5.657,63	12.383,20	213.590,19	191.211,26
2025	2,45	6.164,10	23,25	19.969,10	42.742,81	5.764,39	12.616,87	210.351,98	192.485,98
2026	2,58	6.503,13	24,53	21.067,40	39.366,13	5.873,16	12.854,95	207.423,10	193.822,36
2027	2,72	6.860,80	25,87	22.226,11	36.256,20	5.983,99	13.097,53	204.781,67	195.223,64
2028	2,87	7.238,15	27,30	23.448,55	33.391,96	6.096,91	13.344,68	202.407,69	196.693,22
2029	3,03	7.636,24	28,80	24.738,22	30.754,00	6.211,95	13.596,49	200.282,88	198.234,71
2030	3,20	8.056,24	30,38	26.098,82	28.324,43	6.329,17	13.853,06	198.390,52	199.851,88
2031	3,37	8.499,33	32,05	27.534,26	26.086,80	6.448,61	14.114,46	196.715,42	201.548,72

Annual petrol price increase: 5,5% Annaul battery cost depreciation: 8%
Annual electricty price increase: 5,5%

Scenario 2

Year	Fuel cost	kWh/year	Fuel cost	litres/year	Battery	Maintenance		Total costs	
Scenario 2	EV	2519	ICE	859	EV	EV	ICE	EV	ICE
2012	1,22	3.073,18	11,59	9.955,81	129.779,32	4.283,10	9.784,35	292.816,28	179.640,16
2013	1,34	3.380,50	12,75	10.951,39	118.964,42	4.447,66	9.989,82	282.473,26	180.841,21
2014	1,48	3.718,55	14,02	12.046,53	109.050,76	4.618,55	10.199,61	273.068,53	182.146,14
2015	1,62	4.090,40	15,43	13.251,18	97.334,49	4.796,00	10.408,00	261.901,57	183.559,18
2016	1,79	4.499,44	16,97	14.576,30	89.645,07	4.877,53	10.604,29	254.702,72	185.080,60
2017	1,96	4.949,39	18,67	16.033,93	82.563,11	4.960,45	10.804,29	248.153,62	186.738,22
2018	2,16	5.444,33	20,53	17.637,32	76.040,62	5.044,78	11.008,06	242.210,40	188.545,39
2019	2,38	5.988,76	22,59	19.401,06	70.033,41	5.130,54	11.215,67	236.833,39	190.516,73
2020	2,62	6.587,63	24,84	21.341,16	64.500,77	5.250,00	11.491,00	232.019,09	192.732,16
2021	2,88	7.246,40	27,33	23.475,28	59.405,21	5.349,07	11.707,84	227.681,36	195.083,11
2022	3,16	7.971,04	30,06	25.822,81	54.712,20	5.450,00	11.928,76	223.813,92	197.651,57
2023	3,48	8.768,14	33,07	28.405,09	50.389,94	5.552,85	12.153,86	220.391,60	200.458,95
2024	3,83	9.644,96	36,37	31.245,60	46.409,13	5.657,63	12.383,20	217.392,39	203.528,80
2025	4,21	10.609,45	40,01	34.370,16	42.742,81	5.764,39	12.616,87	214.797,33	206.887,03
2026	4,63	11.670,40	44,01	37.807,17	39.366,13	5.873,16	12.854,95	212.590,36	210.562,12
2027	5,10	12.837,44	48,41	41.587,89	36.256,20	5.983,99	13.097,53	210.758,31	214.585,41
2028	5,61	14.121,18	53,26	45.746,68	33.391,96	6.096,91	13.344,68	209.290,73	218.991,35
2029	6,17	15.533,30	58,58	50.321,35	30.754,00	6.211,95	13.596,49	208.179,93	223.817,84
2030	6,78	17.086,63	64,44	55.353,48	28.324,43	6.329,17	13.853,06	207.420,91	229.106,54
2031	7,46	18.795,29	70,88	60.888,83	26.086,80	6.448,61	14.114,46	207.011,38	234.903,29

Annual petrol price increase: 10% Annual battery cost depreciation: 8%
Annual electricty price increase: 10%

Scenario 3

Year	Fuel cost	kWh/year	Fuel cost	litres/year	Battery	Maintenance		Total costs	
Scenario 3	EV	2519	ICE	859	EV	EV	ICE	EV	ICE
2012	1,22	3.073,18	11,59	9.955,81	129.779,32	4.283,10	9.784,35	292.816,28	179.640,16
2013	1,34	3.380,50	12,75	10.951,39	114.205,80	4.447,66	9.989,82	277.714,64	180.841,21
2014	1,48	3.718,55	14,02	12.046,53	100.501,11	4.618,55	10.199,61	264.518,88	182.146,14
2015	1,62	4.090,40	15,43	13.251,18	88.440,97	4.796,00	10.408,00	253.008,06	183.559,18
2016	1,79	4.499,44	16,97	14.576,30	77.828,06	4.877,53	10.604,29	242.885,71	185.080,60
2017	1,96	4.949,39	18,67	16.033,93	68.488,69	4.960,45	10.804,29	234.079,21	186.738,22
2018	2,16	5.444,33	20,53	17.637,32	60.270,05	5.044,78	11.008,06	226.439,83	188.545,39
2019	2,38	5.988,76	22,59	19.401,06	53.037,64	5.130,54	11.215,67	219.837,62	190.516,73
2020	2,62	6.587,63	24,84	21.341,16	46.673,12	5.250,00	11.491,00	214.191,44	192.732,16
2021	2,88	7.246,40	27,33	23.475,28	41.072,35	5.349,07	11.707,84	209.348,49	195.083,11
2022	3,16	7.971,04	30,06	25.822,81	36.143,67	5.450,00	11.928,76	205.245,39	197.651,57
2023	3,48	8.768,14	33,07	28.405,09	31.806,43	5.552,85	12.153,86	201.808,09	200.458,95
2024	3,83	9.644,96	36,37	31.245,60	27.989,66	5.657,63	12.383,20	198.972,92	203.528,80
2025	4,21	10.609,45	40,01	34.370,16	24.630,90	5.764,39	12.616,87	196.685,41	206.887,03
2026	4,63	11.670,40	44,01	37.807,17	21.675,19	5.873,16	12.854,95	194.899,43	210.562,12
2027	5,10	12.837,44	48,41	41.587,89	19.074,17	5.983,99	13.097,53	193.576,27	214.585,41
2028	5,61	14.121,18	53,26	45.746,68	16.785,27	6.096,91	13.344,68	192.684,03	218.991,35
2029	6,17	15.533,30	58,58	50.321,35	14.771,03	6.211,95	13.596,49	192.196,97	223.817,84
2030	6,78	17.086,63	64,44	55.353,48	12.998,51	6.329,17	13.853,06	192.094,99	229.106,54
2031	7,46	18.795,29	70,88	60.888,83	11.438,69	6.448,61	14.114,46	192.363,26	234.903,29

Annual petrol price increase: 10% | Annual battery cost depreciation: 12%

Annual electricty price increase: 10%

Scenario 4

Year	Fuel cost	kWh/year	Fuel cost	litres/year	Battery	Maintenance		Total costs	
Scenario 4	EV	2519	ICE	859	EV	EV	ICE	EV	ICE
2012	1,22	3.073,18	11,59	9.955,81	129.779,32	4.283,10	9.784,35	292.816,28	179.640,16
2013	1,29	3.242,20	12,75	10.951,39	114.205,80	4.447,66	9.989,82	277.576,35	180.841,21
2014	1,36	3.420,53	14,02	12.046,53	100.501,11	4.618,55	10.199,61	264.220,86	182.146,14
2015	1,43	3.608,66	15,43	13.251,18	88.440,97	4.796,00	10.408,00	252.526,31	183.559,18
2016	1,51	3.807,13	16,97	14.576,30	77.828,06	4.877,53	10.604,29	242.193,40	185.080,60
2017	1,59	4.016,52	18,67	16.033,93	68.488,69	4.960,45	10.804,29	233.146,34	186.738,22
2018	1,68	4.237,43	20,53	17.637,32	60.270,05	5.044,78	11.008,06	225.232,94	188.545,39
2019	1,77	4.470,49	22,59	19.401,06	53.037,64	5.130,54	11.215,67	218.319,35	190.516,73
2020	1,87	4.716,37	24,84	21.341,16	46.673,12	5.250,00	11.491,00	212.320,17	192.732,16
2021	1,98	4.975,77	27,33	23.475,28	41.072,35	5.349,07	11.707,84	207.077,86	195.083,11
2022	2,08	5.249,44	30,06	25.822,81	36.143,67	5.450,00	11.928,76	202.523,79	197.651,57
2023	2,20	5.538,15	33,07	28.405,09	31.806,43	5.552,85	12.153,86	198.578,11	200.458,95
2024	2,32	5.842,75	36,37	31.245,60	27.989,66	5.657,63	12.383,20	195.170,72	203.528,80
2025	2,45	6.164,10	40,01	34.370,16	24.630,90	5.764,39	12.616,87	192.240,07	206.887,03
2026	2,58	6.503,13	44,01	37.807,17	21.675,19	5.873,16	12.854,95	189.732,16	210.562,12
2027	2,72	6.860,80	48,41	41.587,89	19.074,17	5.983,99	13.097,53	187.599,64	214.585,41
2028	2,87	7.238,15	53,26	45.746,68	16.785,27	6.096,91	13.344,68	185.801,00	218.991,35
2029	3,03	7.636,24	58,58	50.321,35	14.771,03	6.211,95	13.596,49	184.299,91	223.817,84
2030	3,20	8.056,24	64,44	55.353,48	12.998,51	6.329,17	13.853,06	183.064,60	229.106,54
2031	3,37	8.499,33	70,88	60.888,83	11.438,69	6.448,61	14.114,46	182.067,30	234.903,29

Annual petrol price increase: 10% | Annual battery cost depreciation: 12%

Annual electricty price increase: 5,5%

Scenario 5

Year	Fuel cost	kWh/year	Fuel cost	litres/year	Battery	Maintenance		Total costs	
Scenario 5	EV	2519	ICE	859	EV	EV	ICE	EV	ICE
2012	1,22	3.073,18	11,59	9.955,81	129.779,32	4.283,10	9.784,35	281.022,60	179.640,16
2013	1,29	3.242,20	12,75	10.951,39	114.205,80	4.447,66	9.989,82	265.782,67	180.841,21
2014	1,36	3.420,53	14,02	12.046,53	100.501,11	4.618,55	10.199,61	252.427,18	182.146,14
2015	1,43	3.608,66	15,43	13.251,18	88.440,97	4.796,00	10.408,00	240.732,63	183.559,18
2016	1,51	3.807,13	16,97	14.576,30	77.828,06	4.877,53	10.604,29	230.399,72	185.080,60
2017	1,59	4.016,52	18,67	16.033,93	68.488,69	4.960,45	10.804,29	221.352,66	186.738,22
2018	1,68	4.237,43	20,53	17.637,32	60.270,05	5.044,78	11.008,06	213.439,26	188.545,39
2019	1,77	4.470,49	22,59	19.401,06	53.037,64	5.130,54	11.215,67	206.525,67	190.516,73
2020	1,87	4.716,37	24,84	21.341,16	46.673,12	5.250,00	11.491,00	200.526,49	192.732,16
2021	1,98	4.975,77	27,33	23.475,28	41.072,35	5.349,07	11.707,84	195.284,19	195.083,11
2022	2,08	5.249,44	30,06	25.822,81	36.143,67	5.450,00	11.928,76	190.730,11	197.651,57
2023	2,20	5.538,15	33,07	28.405,09	31.806,43	5.552,85	12.153,86	186.784,43	200.458,95
2024	2,32	5.842,75	36,37	31.245,60	27.989,66	5.657,63	12.383,20	183.377,04	203.528,80
2025	2,45	6.164,10	40,01	34.370,16	24.630,90	5.764,39	12.616,87	180.446,39	206.887,03
2026	2,58	6.503,13	44,01	37.807,17	21.675,19	5.873,16	12.854,95	177.938,48	210.562,12
2027	2,72	6.860,80	48,41	41.587,89	19.074,17	5.983,99	13.097,53	175.805,96	214.585,41
2028	2,87	7.238,15	53,26	45.746,68	16.785,27	6.096,91	13.344,68	174.007,32	218.991,35
2029	3,03	7.636,24	58,58	50.321,35	14.771,03	6.211,95	13.596,49	172.506,23	223.817,84
2030	3,20	8.056,24	64,44	55.353,48	12.998,51	6.329,17	13.853,06	171.270,92	229.106,54
2031	3,37	8.499,33	70,88	60.888,83	11.438,69	6.448,61	14.114,46	170.273,63	234.903,29

Annual petrol price increase: 10% Annual battery cost depreciation: 12%
Annual electricty price increase: 5,5%
Including incentives of R 11 793 (average EU incentive per year) every year since vehicle is purchased

Scenario 6

Year	Fuel cost	kWh/year	Fuel cost	litres/year	Battery	Maintenance		Total costs	
Scenario 6	EV	2519	ICE	859	EV	EV	ICE	EV	ICE
2012	1,22	3.073,18	11,59	9.955,81	129.779,32	4.283,10	9.784,35	281.022,60	179.640,16
2013	1,29	3.242,20	12,75	10.951,39	114.205,80	4.447,66	9.989,82	265.782,67	180.841,21
2014	1,36	3.420,53	14,02	12.046,53	100.501,11	4.618,55	10.199,61	252.427,18	182.146,14
2015	1,43	3.608,66	15,43	13.251,18	88.440,97	4.796,00	10.408,00	240.732,63	183.559,18
2016	1,51	3.807,13	16,97	14.576,30	77.828,06	4.877,53	10.604,29	230.399,72	185.080,60
2017	1,59	4.016,52	18,67	16.033,93	68.488,69	4.960,45	10.804,29	233.146,34	186.738,22
2018	1,68	4.237,43	20,53	17.637,32	60.270,05	5.044,78	11.008,06	225.232,94	188.545,39
2019	1,77	4.470,49	22,59	19.401,06	53.037,64	5.130,54	11.215,67	218.319,35	190.516,73
2020	1,87	4.716,37	24,84	21.341,16	46.673,12	5.250,00	11.491,00	212.320,17	192.732,16
2021	1,98	4.975,77	27,33	23.475,28	41.072,35	5.349,07	11.707,84	207.077,86	195.083,11
2022	2,08	5.249,44	30,06	25.822,81	36.143,67	5.450,00	11.928,76	202.523,79	197.651,57
2023	2,20	5.538,15	33,07	28.405,09	31.806,43	5.552,85	12.153,86	198.578,11	200.458,95
2024	2,32	5.842,75	36,37	31.245,60	27.989,66	5.657,63	12.383,20	195.170,72	203.528,80
2025	2,45	6.164,10	40,01	34.370,16	24.630,90	5.764,39	12.616,87	192.240,07	206.887,03
2026	2,58	6.503,13	44,01	37.807,17	21.675,19	5.873,16	12.854,95	189.732,16	210.562,12
2027	2,72	6.860,80	48,41	41.587,89	19.074,17	5.983,99	13.097,53	187.599,64	214.585,41
2028	2,87	7.238,15	53,26	45.746,68	16.785,27	6.096,91	13.344,68	185.801,00	218.991,35
2029	3,03	7.636,24	58,58	50.321,35	14.771,03	6.211,95	13.596,49	184.299,91	223.817,84
2030	3,20	8.056,24	64,44	55.353,48	12.998,51	6.329,17	13.853,06	183.064,60	229.106,54
2031	3,37	8.499,33	70,88	60.888,83	11.438,69	6.448,61	14.114,46	182.067,30	234.903,29

Annual petrol price increase: 10% Annual battery cost depreciation: 12%
Annual electricty price increase: 5,5%
Including incentives of R 11 793 (average EU incentive per year) only for the first 5 years to stimulate market uptake.
After a period of 5 years no more incentives

Scenario 7

Year	Fuel cost	kWh/year	Fuel cost	litres/year	Battery	Maintenance		Total costs	
Scenario 7	EV	2519	ICE	859	EV	EV	ICE	EV	ICE
2012	1,22	3.073,18	11,59	9.955,81	129.779,32	4.283,10	9.784,35	292.816,28	179.640,16
2013	1,46	3.687,82	12,75	10.951,39	114.205,80	4.447,66	9.989,82	278.021,96	180.841,21
2014	1,76	4.425,38	14,02	12.046,53	100.501,11	4.618,55	10.199,61	265.225,71	182.146,14
2015	2,11	5.310,46	15,43	13.251,18	88.440,97	4.796,00	10.408,00	254.228,11	183.559,18
2016	2,53	6.372,55	16,97	14.576,30	77.828,06	4.877,53	10.604,29	244.758,81	185.080,60
2017	3,04	7.647,06	18,67	16.033,93	68.488,69	4.960,45	10.804,29	236.776,87	186.738,22
2018	3,64	9.176,47	20,53	17.637,32	60.270,05	5.044,78	11.008,06	230.171,97	188.545,39
2019	4,37	11.011,76	22,59	19.401,06	53.037,64	5.130,54	11.215,67	224.860,62	190.516,73
2020	5,25	13.214,11	24,84	21.341,16	46.673,12	5.250,00	11.491,00	220.817,91	192.732,16
2021	6,29	15.856,93	27,33	23.475,28	41.072,35	5.349,07	11.707,84	217.959,03	195.083,11
2022	7,55	19.028,32	30,06	25.822,81	36.143,67	5.450,00	11.928,76	216.302,67	197.651,57
2023	9,06	22.833,98	33,07	28.405,09	31.806,43	5.552,85	12.153,86	215.873,94	200.458,95
2024	10,88	27.400,78	36,37	31.245,60	27.989,66	5.657,63	12.383,20	216.728,74	203.528,80
2025	13,05	32.880,94	40,01	34.370,16	24.630,90	5.764,39	12.616,87	218.956,90	206.887,03
2026	15,66	39.457,13	44,01	37.807,17	21.675,19	5.873,16	12.854,95	222.686,16	210.562,12
2027	18,80	47.348,55	48,41	41.587,89	19.074,17	5.983,99	13.097,53	228.087,38	214.585,41
2028	22,56	56.818,26	53,26	45.746,68	16.785,27	6.096,91	13.344,68	235.381,11	218.991,35
2029	27,07	68.181,91	58,58	50.321,35	14.771,03	6.211,95	13.596,49	244.845,58	223.817,84
2030	32,48	81.818,30	64,44	55.353,48	12.998,51	6.329,17	13.853,06	256.826,66	229.106,54
2031	38,98	98.181,95	70,88	60.888,83	11.438,69	6.448,61	14.114,46	271.749,93	234.903,29

Annual petrol price increase: 10% Annual battery cost depreciation: 12%
Annual electricty price increase: 20%

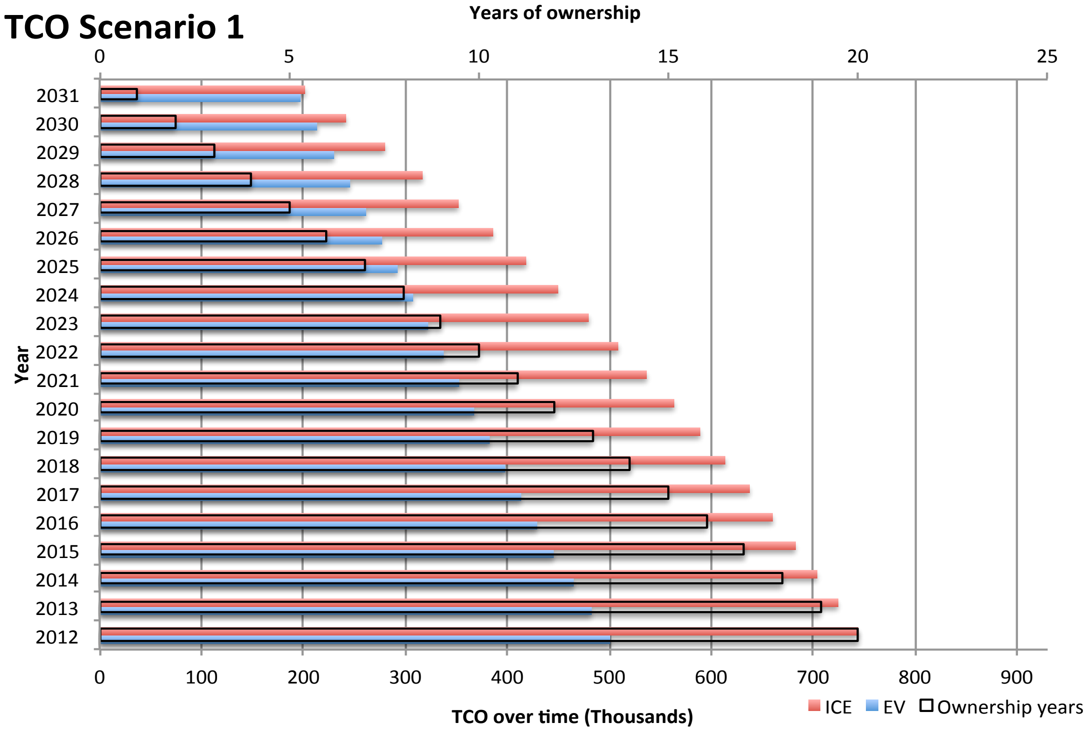
Scenario 8

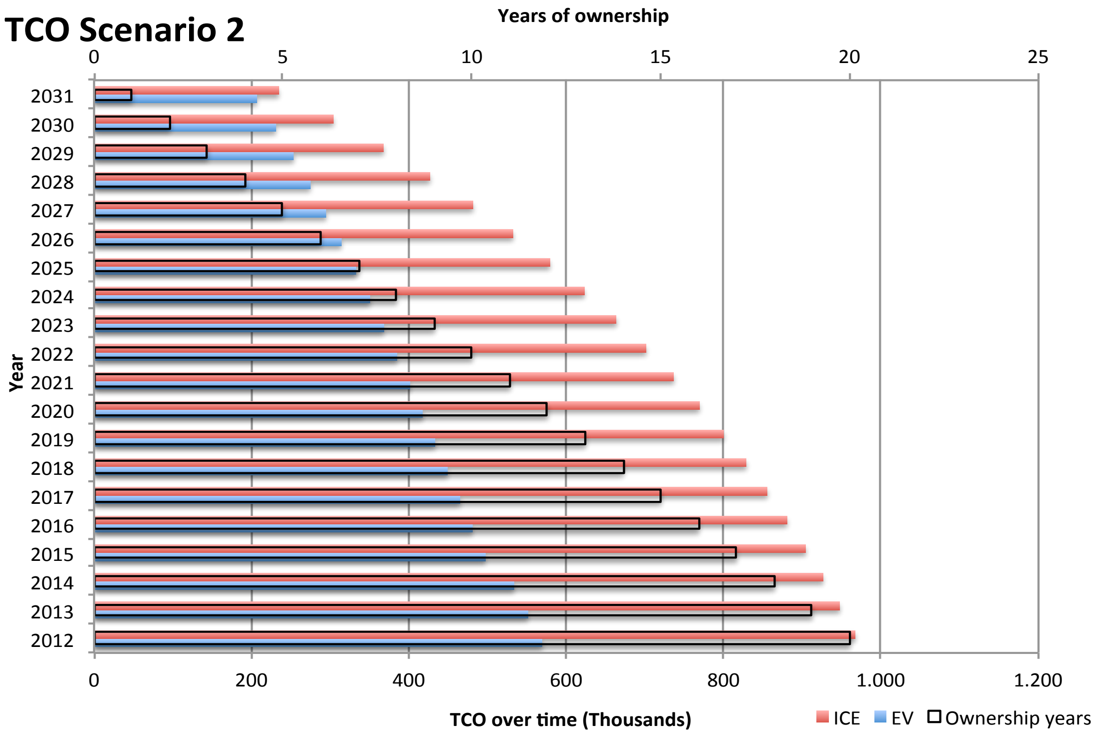
Year	Fuel cost	kWh/year	Fuel cost	litres/year	Battery	Maintenance		Total costs	
Scenario 8	EV	2519	ICE	859	EV	EV	ICE	EV	ICE
2012	1,22	3.073,18	11,59	9.955,81	129.779,32	4.283,10	9.784,35	281.022,60	179.640,16
2013	1,46	3.687,82	12,75	10.951,39	114.205,80	4.447,66	9.989,82	266.228,28	180.841,21
2014	1,76	4.425,38	14,02	12.046,53	100.501,11	4.618,55	10.199,61	253.432,03	182.146,14
2015	2,11	5.310,46	15,43	13.251,18	88.440,97	4.796,00	10.408,00	242.434,43	183.559,18
2016	2,53	6.372,55	16,97	14.576,30	77.828,06	4.877,53	10.604,29	232.965,13	185.080,60
2017	3,04	7.647,06	18,67	16.033,93	68.488,69	4.960,45	10.804,29	236.776,87	186.738,22
2018	3,64	9.176,47	20,53	17.637,32	60.270,05	5.044,78	11.008,06	230.171,97	188.545,39
2019	4,37	11.011,76	22,59	19.401,06	53.037,64	5.130,54	11.215,67	224.860,62	190.516,73
2020	5,25	13.214,11	24,84	21.341,16	46.673,12	5.250,00	11.491,00	220.817,91	192.732,16
2021	6,29	15.856,93	27,33	23.475,28	41.072,35	5.349,07	11.707,84	217.959,03	195.083,11
2022	7,55	19.028,32	30,06	25.822,81	36.143,67	5.450,00	11.928,76	216.302,67	197.651,57
2023	9,06	22.833,98	33,07	28.405,09	31.806,43	5.552,85	12.153,86	215.873,94	200.458,95
2024	10,88	27.400,78	36,37	31.245,60	27.989,66	5.657,63	12.383,20	216.728,74	203.528,80
2025	13,05	32.880,94	40,01	34.370,16	24.630,90	5.764,39	12.616,87	218.956,90	206.887,03
2026	15,66	39.457,13	44,01	37.807,17	21.675,19	5.873,16	12.854,95	222.686,16	210.562,12
2027	18,80	47.348,55	48,41	41.587,89	19.074,17	5.983,99	13.097,53	228.087,38	214.585,41
2028	22,56	56.818,26	53,26	45.746,68	16.785,27	6.096,91	13.344,68	235.381,11	218.991,35
2029	27,07	68.181,91	58,58	50.321,35	14.771,03	6.211,95	13.596,49	244.845,58	223.817,84
2030	32,48	81.818,30	64,44	55.353,48	12.998,51	6.329,17	13.853,06	256.826,66	229.106,54
2031	38,98	98.181,95	70,88	60.888,83	11.438,69	6.448,61	14.114,46	271.749,93	234.903,29

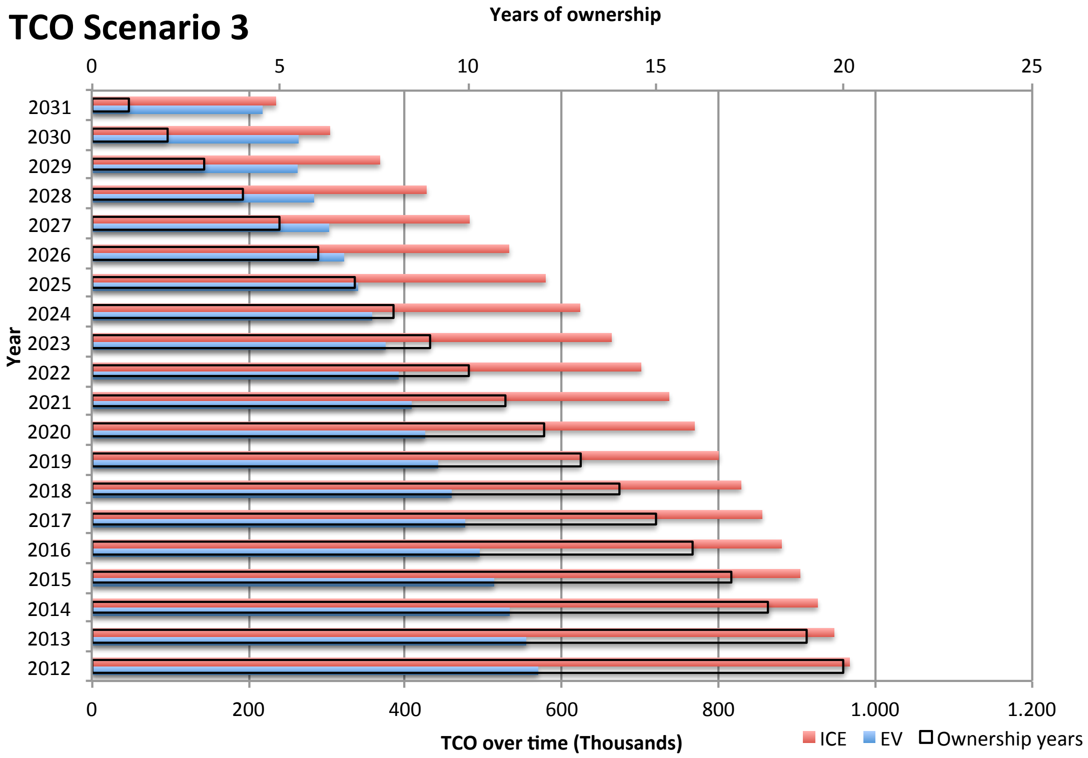
Annual petrol price increase: 10% Annual battery cost depreciation: 12%
Annual electricty price increase: 20%
Including incentives of R 11 793 (average EU incentive per year) only for the first 5 years to stimulate market uptake.
After a period of 5 years no more incentives

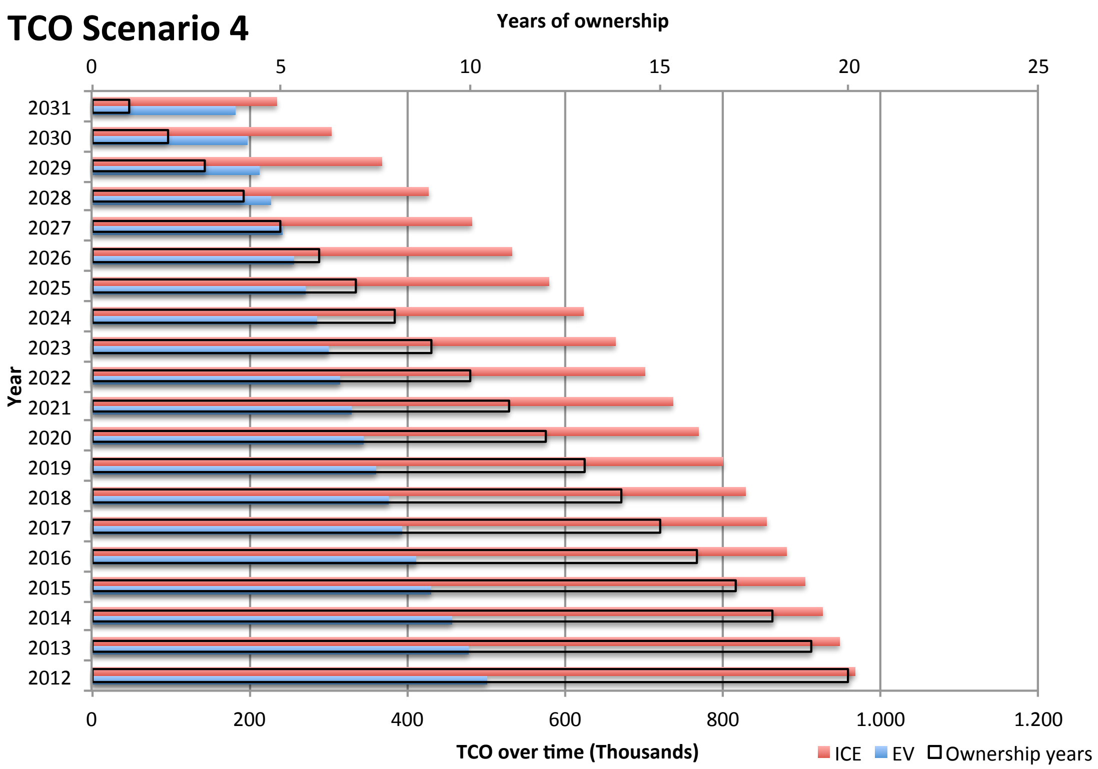
B3: Total cost of ownership comparison over time

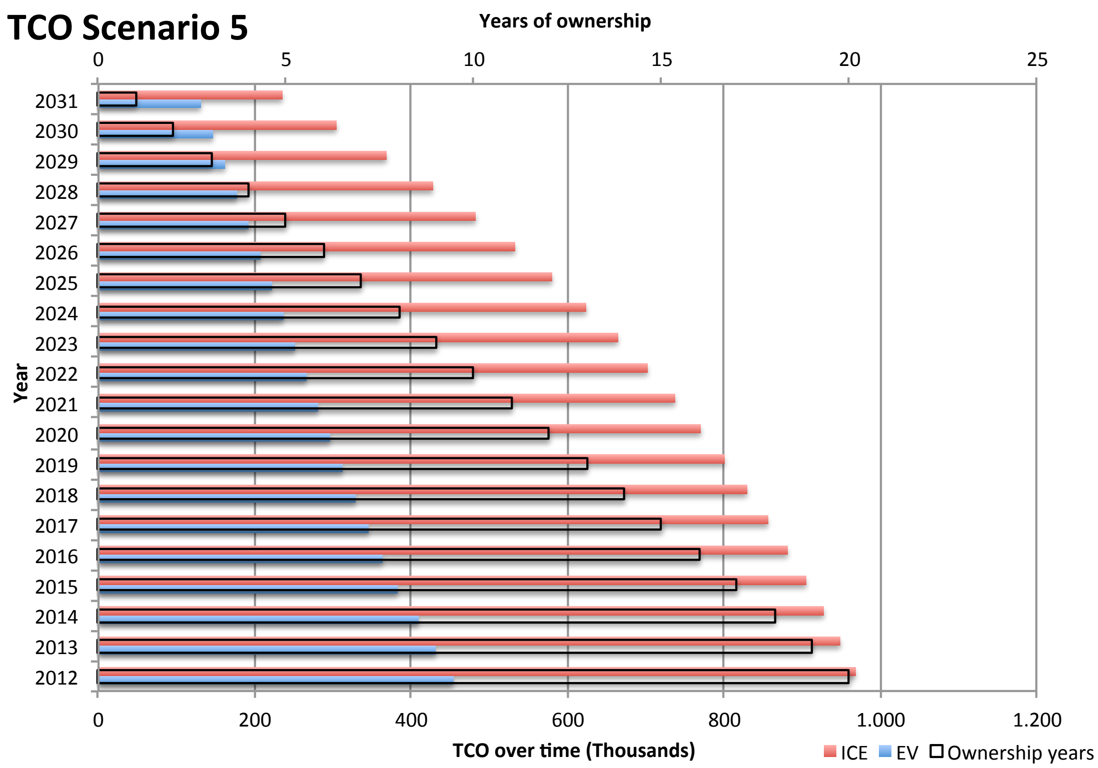
The TCO is calculated overtime. For instance, if a vehicle is purchased in 2012 the TCO overtime is calculated per scenario until 2031. So in that case the costs between 2012-2031 have been added up and so on for the other years.

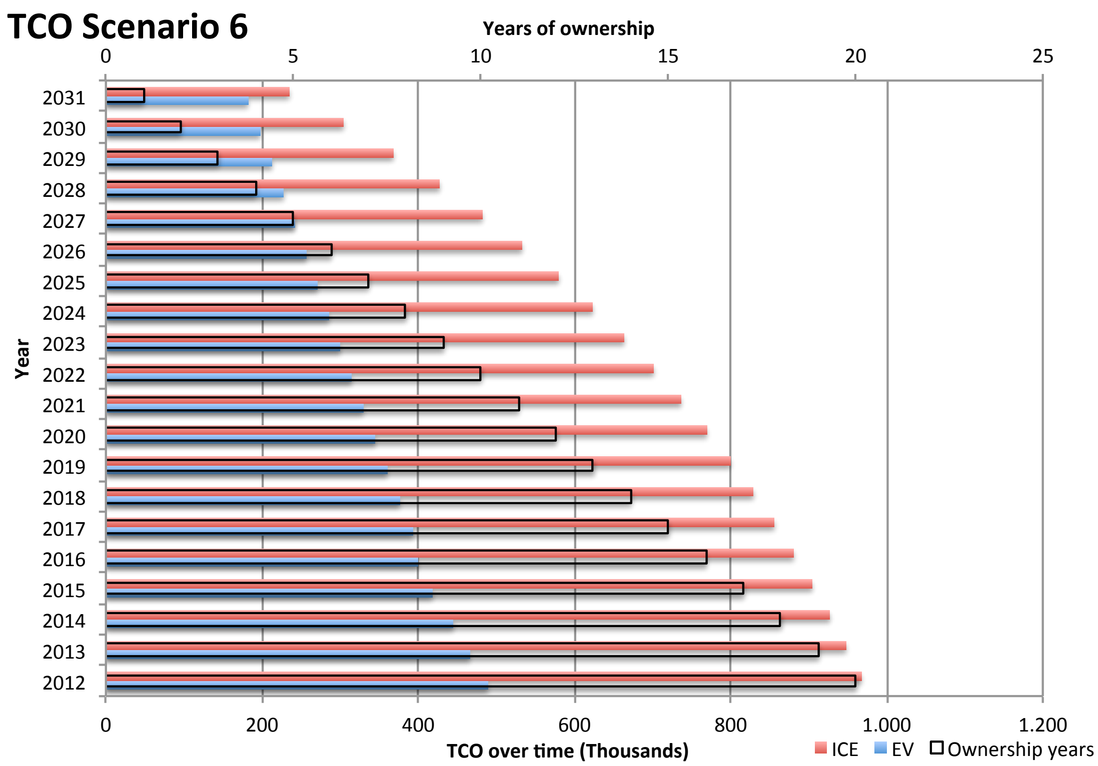


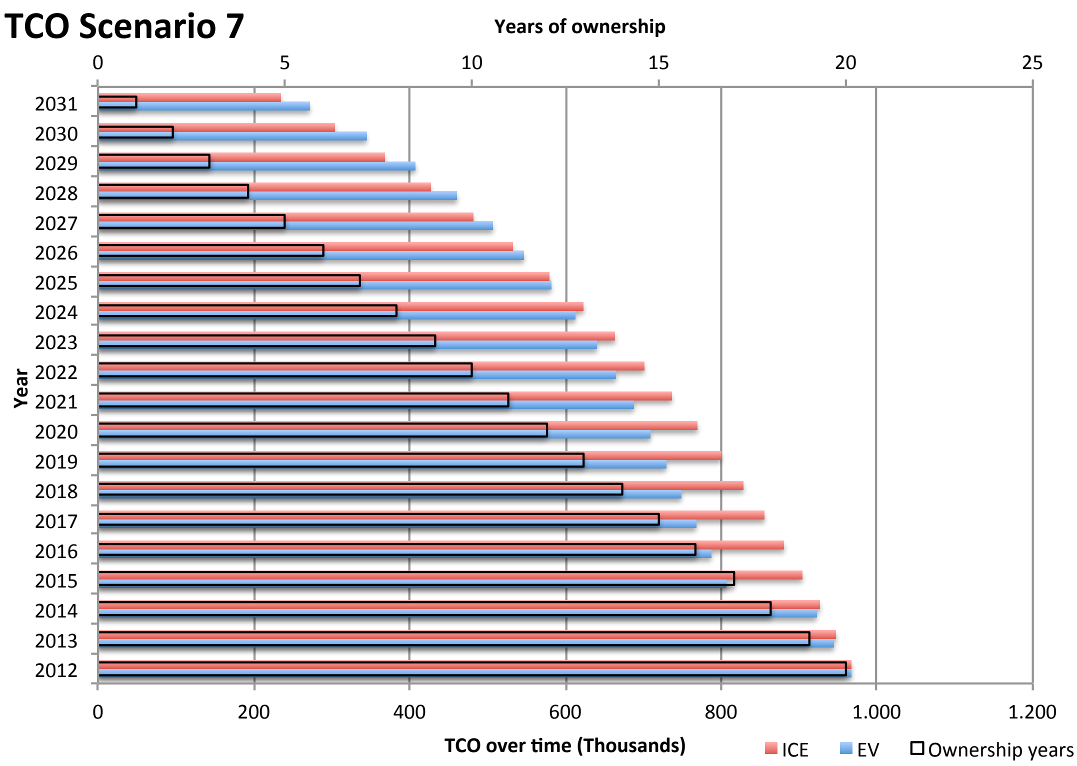


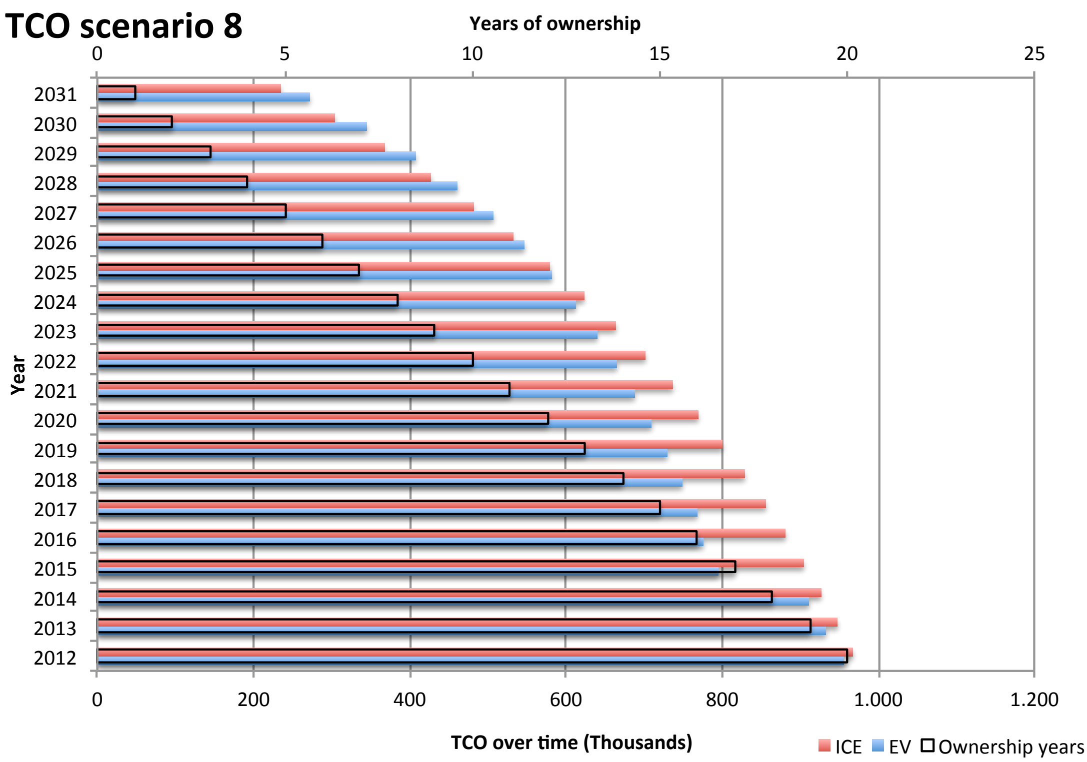

TCO Scenario 3
Years of ownership
0
5
10
15
20
25
2031
2030
2029
2028
2027
2026
2025
2024
2023
2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
Year
0
200
400
600
800
1.000
1.200
TCO over time (Thousands)
ICE
EV
Ownership years


TCO Scenario 4
Years of ownership
0
5
10
15
20
25
2031
2030
2029
2028
2027
2026
2025
2024
2023
2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
Year
0
200
400
600
800
1.000
1.200
TCO over time (Thousands)
ICE
EV
Ownership years


TCO Scenario 5
Years of ownership
0
5
10
15
20
25
2031
2030
2029
2028
2027
2026
2025
2024
2023
2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
Year
0
200
400
600
800
1.000
1.200
TCO over time (Thousands)
ICE
EV
Ownership years


TCO Scenario 6
Years of ownership
0
5
10
15
20
25
2031
2030
2029
2028
2027
2026
2025
2024
2023
2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
Year
0
200
400
600
800
1.000
1.200
TCO over time (Thousands)
ICE
EV
Ownership years


TCO Scenario 7
Years of ownership
0
5
10
15
20
25
2031
2030
2029
2028
2027
2026
2025
2024
2023
2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
Year
0
200
400
600
800
1.000
1.200
TCO over time (Thousands)
ICE
EV
Ownership years


TCO scenario 8
Years of ownership
0
5
10
15
20
25
2031
2030
2029
2028
2027
2026
2025
2024
2023
2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
Year
0
200
400
600
800
1.000
1.200
TCO over time (Thousands)
ICE
EV
Ownership years